metal treatment

Vol. 27 : No. 177 JUNE, 1960 Price 2/6

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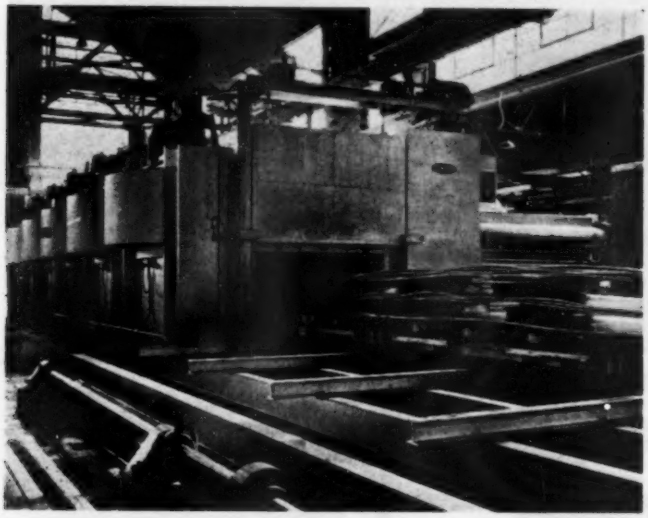
G.W.B. high-rating furnace cuts cycle times



Accommodates slab lengths of 65 ft. x 6 ft. 6 ins.

In the recent large-scale development programme spread over some 30 months, the Northern Aluminium Co. Ltd. has introduced considerable quantities of new plant and handling equipment. A new batch-type furnace, designed and erected by G.W.B. at the Banbury Works of Northern Aluminium, was part of this programme. Production at Banbury, both in aluminium and a variety of aluminium alloys, embraces a wide range of sheets, discs and coils.

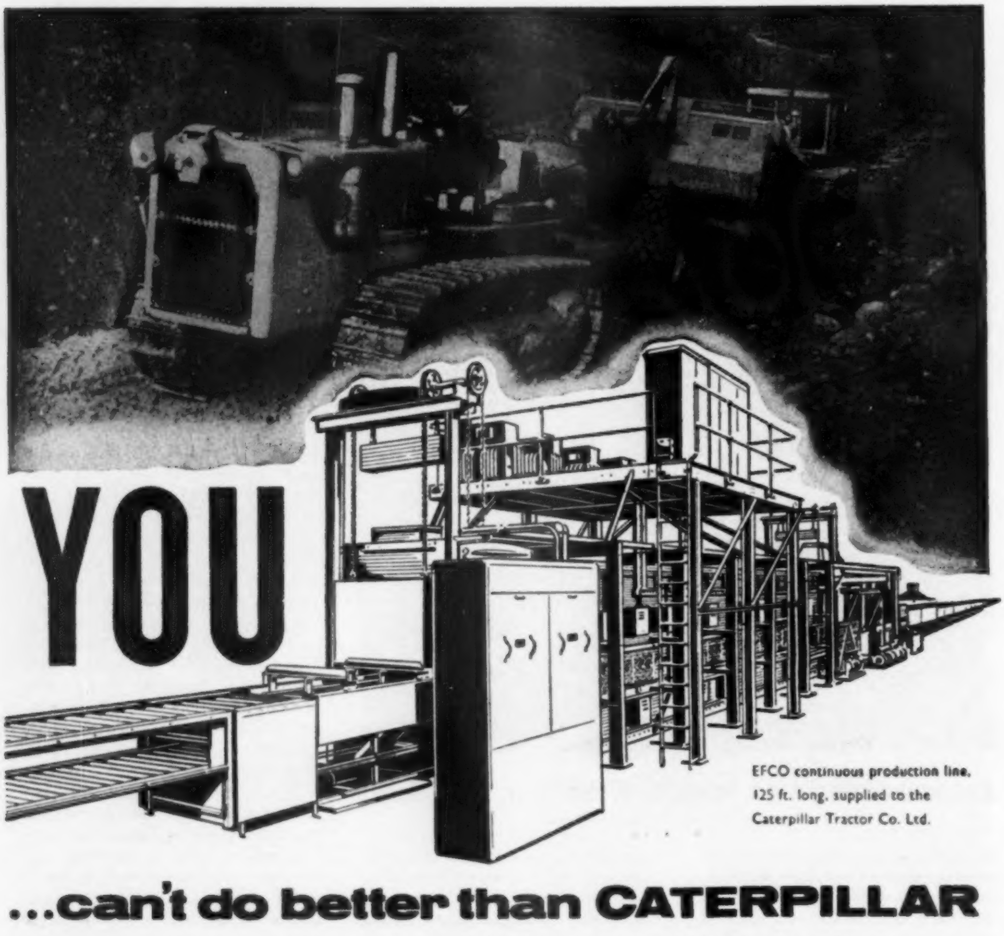
Owing to the occurrence of a certain amount of work-hardening (8 in. thick ingots of aluminium are hot rolled to a thickness of approximately 0.3 to 0.5 in.) it is necessary for slabs to be annealed prior to being cold rolled to lighter gauges. The rating of this G.W.B. furnace is 1,000 kW and it comprises six independent and automatically controlled zones of equal length. Rating distribution is as follows: Zone 1 220 kW, Zones 2-5 150 kW each, Zone 6 180 kW. *Owing to the high rating, cycle times as low as 4 hours are regularly obtained.* The maximum temperature of the furnace is 600°C, normal operating temperature being rather lower than this figure.

The heating chamber is lined throughout with heat-resisting alloy, backed by a thick wall of Moler insulating bricks, thus reducing heat losses to a minimum. The furnace casing is constructed from sheet mild steel braced with steel rolled sections and fitted with a mild steel front plate. A cast-framed, refractory faced, fully insulated and counter-balanced door, driven by electric motor, is sealed against the furnace face by pneumatic clamps, thus minimizing heat losses at the furnace entrance. The furnace is supported clear of the ground.

Nickel-chromium strip heating elements, arranged on removable plugs, are situated in the roof chamber, and each zone is fitted with a forced-air circulation system directed cross-flow from the fan, through the heating elements contained in the ducted portion of heating chamber, down into the treatment chamber, and back into the fan for re-circulation. Radiation on to the charge is prevented by a special baffle fitted in the roof chamber to separate the heating elements from the actual working area. Baffles, each independently adjustable and extending the full length of the chamber on each side, direct the air flow to give desired flow characteristics and equalise the temperature throughout the working chamber.

Six air circulating fans are fitted, one per zone. A cooling chamber, similar in size to the heating chamber is incorporated in the unit. A G.W.B. single track charging machine serves both the furnace and the cooling chamber.

As a result of the modernisation, the new rolling mills can roll aluminium sheet to a maximum width of 6 ft. 6 in.; the previous maximum had been 5 ft. The G.W.B. furnace naturally was designed to handle this increased width. It can accommodate loads up to 16 tons for slab lengths of 65 ft. The furnace is normally used to treat slabs of heavy-duty materials for varied employment: Aircraft, coachwork, decorative finishes, car trimming and a host of other uses.



EFCO continuous production line, 125 ft. long, supplied to the Caterpillar Tractor Co. Ltd.

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That is why Efco were chosen to provide the new production line in which components are given precise and vital heat treatment.

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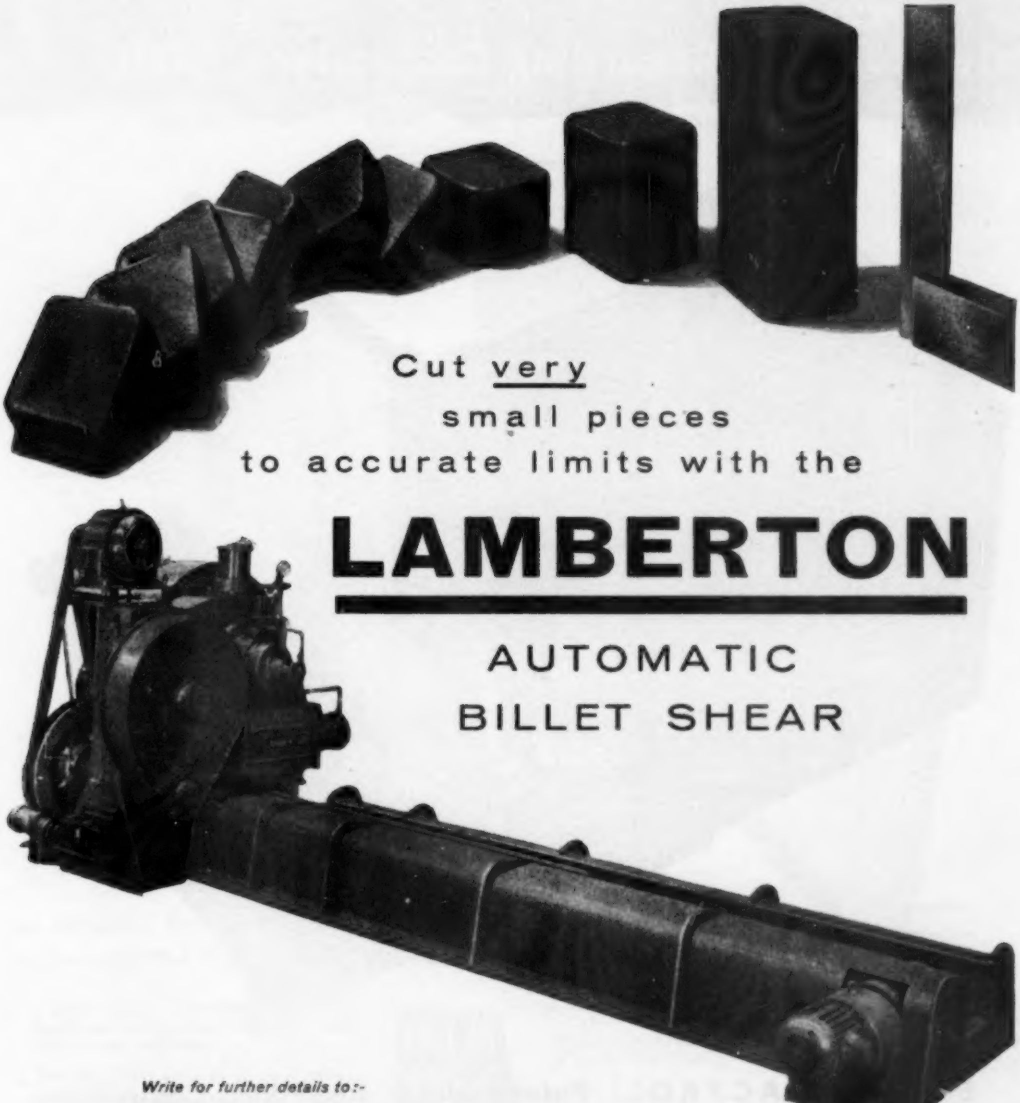
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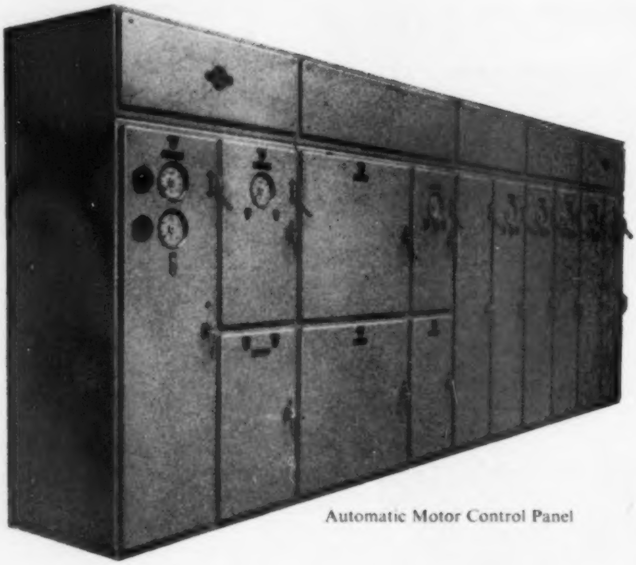


Automatic Motor Control Panel

A FLEXIBLE AUTOMATIC STOVING OVEN

Output doubled and costs halved at Brookhirst Igranic

The names Igranic and Brookhirst have been synonymous with electrical control for three decades and, following the trend towards applied automation in industry, the output of electric motor control equipment from Brookhirst Igranic Ltd. of Bedford continues to increase at an enormous rate. The Company supplies electric motor control panels and cubicles for every industry. Often the control equipment is installed in corrosive environments and the casing must adequately protect the thousands of electrical connections upon which the continuous operation of a factory might depend.

In the Bedford factory the Company was faced with the problem of satisfactorily stoving paint on a number of different control housings of vastly different size and in many different colours. The existing batch oven could only deal with three housings an hour, took nearly three minutes to load and unload, required an average stoving time of three-quarters of an hour and the estimated cost was 1/3d. per housing. But as Mr. Lincoln, the Production Engineer, said, "Before installing the new oven considerable investigation was made into the costs and performance of the available fuels and, largely because of the economics and cleanliness of the combustion products, it was decided to use a direct gas-fired oven."

In conjunction with Edward Curran of Cardiff, the production engineers designed and planned an oven which would meet their requirements and then had it constructed to their specification. Basically these requirements were:—

(*a*) Flexibility of component size, surface area and ultimate finish.

(*b*) Complete safety for the operatives.

(*c*) Automatic control with provision for over-riding manual control for awkward work pieces.

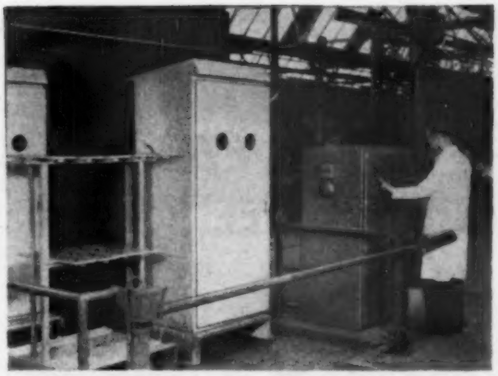
(*d*) Economic fuel consumption.

The oven as ultimately erected is shown in the illustration. Steel components are given a precise chemical treatment to ensure cleanliness of the metal particularly at the welds. From the cleaning plant these components pass to a boothless spraying unit where powerful under-floor exhaust fans extract overspray. Thence they pass to the stoving oven.

The B H I Production Engineers decided on a fixed time/temperature stoving schedule of 21 minutes at 300°F. Then their paint suppliers delivered primer and finishing coats in a variety of colours which could be fully stoved within this period. As a result, not only did this gas-fired oven offer flexibility in component size but also in component colour.

The sprayed components are brought up to the oven, the bottom of which is formed by a floor conveyor. The safety gate is raised and during this period there is no possibility of movement of the conveyor. The component is loaded on to the conveyor and the gate is closed. Already there are three batches within the oven itself. At the end of seven minutes, the entrance door designed as a roll shutter is lifted. Simultaneously the exit door opens. The conveyor moves forward taking the unit to be stoved into the oven and at the same time removing a unit which has been stoved for 21 minutes from the exit end. The doors again close automatically and this cycle takes place continuously throughout the day. Should a housing which has been removed from the oven not be taken from the conveyor, there would be a danger that at the end of a further seven minutes, another load from the oven would collide with it and when the oven door closed, damage to the doors and the unit would be incurred. Thus each exit load passes across a beam of light focussed upon a photo-electric cell. If the finished unit is not removed within two minutes both a visible and an audible alarm signal are operated.

Sometimes units are so large that they will not conform to the three-space load system adopted for general production work. In such circumstances, the oven can be switched over from automatic to manual operation and used as a normal batch oven. The clock is set for the stoving time required and the doors may be operated singly and the movement of the conveyor controlled manually by switches on the oven control panel which was also designed by the B H I Engineers. Mr. Lincoln then demonstrated what this rigid time/temperature stoving schedule means in practice. "Look at those composite housings, all joined together in a single unit," he said. "When we were on manual control with the old batch oven you often found one unit in the middle of about fifty which was a different colour from the rest—it had to be taken out, the electrical installation removed, the paint stripped off and repainted. The cost and inconvenience were serious to us." He also pointed out that whereas components stoved in the old oven broke down in the salt spray test in five days, now they show only slight signs of breaking after 25 days. He then referred to economics and gave the comparison below of the performance of the old batch oven with the new one.



Checking the timer control panel and showing housing about to enter oven.

Collecting the stoved product from the outlet side.

	Old	New
1. Maximum output per hour	3 Housings or their equivalent	18 Housings or their equivalent
2. Maximum hourly gas consumption	900 cu. ft.	3,500 cu. ft.
3. Time for loading and unloading	150 seconds	22 seconds
4. Number of housings loaded each time	1, or its equivalent	2, or their equivalent
5. Average time of stoving cycle	45 minutes	20 minutes
6. Average cost per housing	15d.	4d.

One contribution to the reduction in stoving costs per unit was undoubtedly the careful balancing between the extraction and circulation fans, for, if one notes the pyrometer reading when both doors are open, it is found that there is virtually no drop in temperature. "What is more," said Mr. Lincoln, "the gas is so efficient that you can build up the oven temperature from cold in 6 minutes."

Brookhirst Igranic complimented the Eastern Gas Board upon their collaboration and service during the installation of the oven and its subsequent running in, and this is but one example of the co-operation between the Industrial Officers of the Area Gas Boards and manufacturers. These Industrial Officers from up and down the country meet regularly to exchange views, so that whenever a factory has a heat engineering problem, then by consultation with the Area Gas Board it can take advantage of this pooled knowledge. Industrial Officers, in addition, have the benefit of information received regularly from the Industrial Gas Information Bureau, which keeps in touch with new developments in gas utilization throughout the world.

Scottish Gas Board, Edinburgh.
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North Western Gas Board, Manchester.
North Eastern Gas Board, Leeds.
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West Midlands Gas Board, Birmingham.
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South Western Gas Board, Bath

The Gas Council, 1 Grosvenor Place, London, S.W.1.

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metal treatment

and Drop Forging

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CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

British markets

SHOULD Britain export materials and plant to her traditional markets when this enables these countries to themselves become producers? Can this be in her real interest? It is not surprising that this question gives rise to conflicting points of view. Of direct concern to the metal industries, it is a problem which also proves of great interest to the electrical industry—the second largest exporting industry in the U.K. At last month's British Electrical Power Convention the Hon. H. G. Nelson, managing director, the English Electric Co. Ltd., made some interesting points in his address.

Speaking of the opening of local plants in overseas countries, he said: ' In almost every case, within a few years the local factory is taking over more and more lines of manufacturing and in so doing is stopping the export of these particular lines from the British factories.

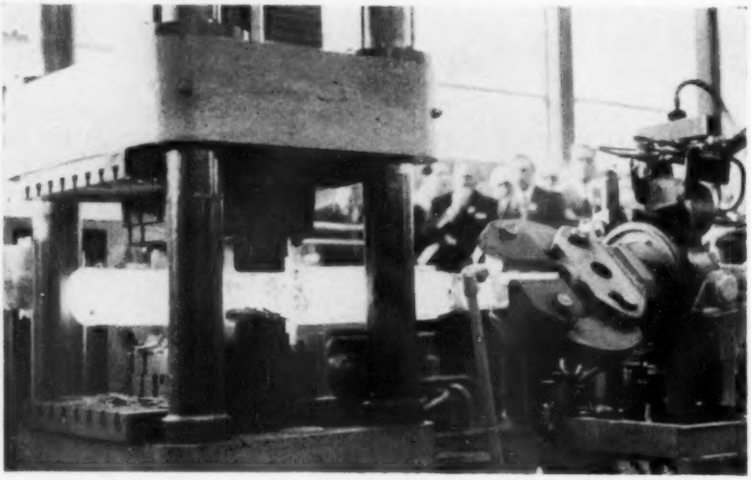
' Some people for this reason believe that industrialization in some of our traditional British markets is against the interest of the British exporter. It is of course true, as has been shown often since the war, that the immediate impact of industrialization in a country is often to destroy the British exporter's market for certain types of goods, but we should not forget that the process of industrialization demands capital goods of a size and complexity which are not available in these developing countries. Whilst it may be poor comfort to a specialist manufacturer of, for example, small industrial motors to realize that the market for steel mill power and control equipment is growing rapidly, from the point of view of the British economy as a whole this type of substitution of products offsets the purely negative effects of industrialization in our export markets.

' Furthermore, the industrialization of any country leads to a rapid rise in the standard of living and in the demand for goods and services of all kinds and therefore to a much wider market. All experience shows that in the long run industrialization breeds a demand for imports of industrial products. It is true that in the early stages the developing country will protect its newly-fledged industries, but as the years go on the costs of that protection become very onerous and pressures develop to open the market once again to imported goods.

' So although the rise of local secondary industry in some of our markets faces us with particular problems, it does not close these markets to us—rather it involves changes in the type of product which we export. As industry becomes more complex, the demand becomes more sophisticated and, in general, the type of capital equipment required always includes a high proportion beyond the scope of its own growing capacity. Even when local production of such equipment is well advanced there is often a strong demand on the British exporter for parts to be incorporated in them.

' The effects on U.K. manufacturing of the changing pattern of international trade are considerable. A primary feature of overseas business is competition from American, Japanese, continental and Soviet bloc equipment, sometimes locally manufactured. Price competition is particularly severe and it is sometimes found that this arises because our designs, based on more exacting specifications, are more elaborate and hence more expensive that those from other countries. In recent years we have sometimes been forced to develop alternative, more economic designs for equipment destined for overseas. This tendency will increase. Sometimes these simpler designs will commend themselves to our home customer also and in other cases we may have to try and establish new specifications which will be acceptable both at home and abroad.

' It should be noted that special development for overseas can be of benefit to the home customer. Overseas trade provides both a spur to undertake research and development work and also the necessary returns required to sustain its cost.'



The BISRA *experimental forge at Sheffield during a demonstration of a precision-controlled 200-ton press interlocked with a remote-controlled manipulator*

All-automatic forging

COMPLETELY AUTOMATIC forging of steel by pre-calculated programme has just been successfully demonstrated in the experimental forge of the British Iron and Steel Research Association at Sheffield—for what is believed to be the first time in any country.

The forging was carried out by a precision controlled 200-ton press interlocked with a fast, remote-controlled, experimental manipulator capable of longitudinal, rotational and lifting movements. Electric controls had been developed for both press and manipulator to ensure fast, accurate operation and to synchronize the movements of the two machines.

During the forging, the press and manipulator were controlled by a programme control unit on which every detail of the schedule of forging operations had been set up. In this schedule, the upper and lower limits of the squeeze for every pass were given, the manipulator feed between strokes was selected, and the manipulation necessary between passes was also stored. The control unit signalled instructions to the press and manipulator in the appropriate sequence.

Faster working shortly

As a consequence, the finished forging in some respects exceeded the best current industrial standards as regards dimensional precision, and, even so, the job was accomplished twice as fast as the best skilled forging crew would be capable of doing. Even faster working will be practicable before very long.

The forging schedule was calculated in advance, from a theory of the change in shape during forging which had been worked out in the laboratory.

This advance in forging technique comes when many firms are already planning to re-equip their forges, in some cases to replace machines dating back to the first world war. At the moment there are probably more forging presses on order in this country than at any previous time; this development of automatic working therefore offers the forging industry a great opportunity to place itself ahead of foreign competition.

New British standard

British standard procedures for obtaining properties of steel at elevated temperatures (*B.S.*3228 : 1960). *Part 2: Rupture strength.*

This new publication forms part of a series of procedures for obtaining the data necessary to determine the properties of steel at elevated temperatures.

Standard procedures ensure that the data obtained will be based on a common method—a prime requisite where the resultant figures are to be included in national standards acceptable to purchasers of steel and of equipment made from it, both in the United Kingdom and overseas. The new standard deals with the method of test; the selection of the samples; test conditions; and the presentation of results.

Copies of this British standard can be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1, price 3*s*. (postage will be charged extra to non-subscribers).

Some effects of grain-size on the mechanical properties of Nimocast 258

F. G. HAYNES, M.Eng., A.I.M., and D. R. WOOD, M.A., A.I.M.

Control of the grain-size of investment-cast test bars of Nimocast 258 has been achieved by vacuum casting at pre-determined pouring temperatures. Room-temperature tensile tests have shown that, within the grain-size range studied, viz. $\ngtr$0·5 mm.–3 mm., there is little variation of strength and ductility. In stress-rupture and rotating-bend-fatigue tests at 750, 870 and 980°C., for periods up to 500 or 1,000 hours, the effect of grain-size variation is also small, although results of long-term tests at 750–870°C. suggest that a fine grain-size is slightly preferable. At room temperature, fine grain-size appears to be detrimental to consistency; it is suggested that this effect may be associated with micro-porosity.
The authors are with the Development and Research Department, the Mond Nickel Co. Ltd.

MANY ENGINEERING APPLICATIONS call for alloys having good mechanical strength at elevated temperatures, and designers have constantly under review the ever-widening range of materials capable of meeting their needs. One of the recently developed nickel-base alloys is Nimocast 258 which, in the cast form, retains more than 70% of its room-temperature tensile strength up to 900°C. Its high resistance to creep, at temperatures up to at least 1,000°C., suggests that the alloy, in various forms, will be useful for gas-turbine applications.

It has often been suggested that grain-size in the as-cast condition may significantly influence the mechanical properties of cast alloys, and the present work was undertaken to evaluate the effects of grain-size on the room-temperature tensile and high-temperature stress-rupture and fatigue properties of Nimocast 258. The investigation covered a range of grain-sizes commonly found in investment castings of the type used for gas-turbine components, and was carried out on investment-cast test bars of suitably small section thickness.

The work was undertaken co-operatively with the De Havilland Aircraft Co. Ltd. and D. Napier & Son Ltd.

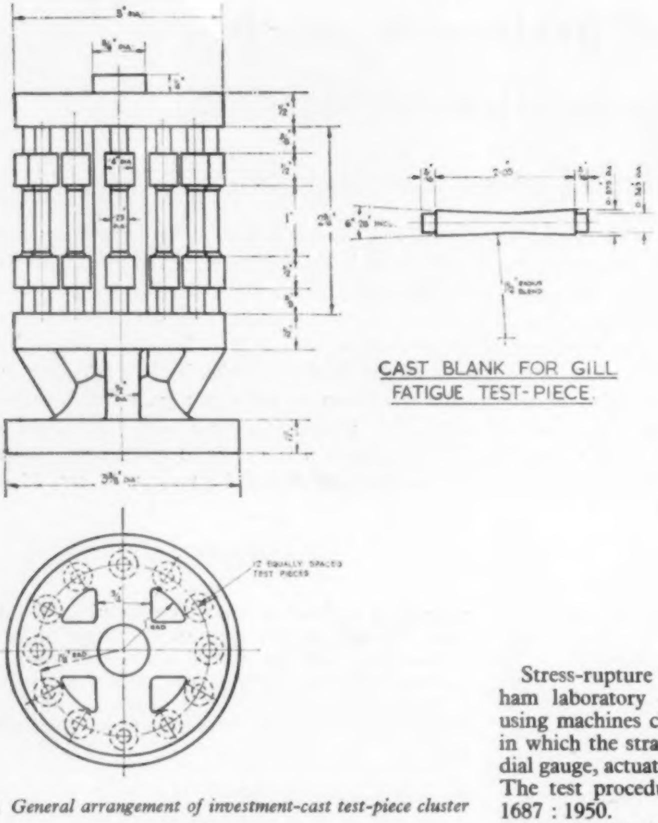
Preparation of samples

Test-pieces were vacuum-cast under a pressure of 10^{-3} mm. Hg in investment moulds (fig. 1) pre-heated to 1,000°C. The equipment used was a VSG 15 Balzer vacuum unit, the furnace lining being pre-formed from pure fused magnesia. Each heat took approximately 15 min. to melt and cast, and each mould was cast from a separate 4½-lb. re-melt of vacuum-melted stock. Four heats of Nimocast 258, having the compositions given in

TABLE 1 *Compositions of materials used*

	Heat No.	Chemical composition %												
		C	Si	Mn	Cr	Co	Fe	Mo	Ti	Al	B	Ca	Pb	Ni
Vacuum-melted stock	V 162	0·19	0·43	0·39	10·3	20·5	1·2	5·3	4·0	5·4	0·017	—	0·0015	Bal.
	V 211	0·21	0·46	0·38	10·6	20·8	1·0	5·3	4·1	5·3	0·012	—	0·0013	,,
	V 236	0·22	—	—	10·4	20·2	—	5·1	4·0	5·2	—	—	—	,,
	V 237	0·26	—	—	10·4	20·0	—	4·8	3·9	5·0	—	—	—	,,
Cast test-bars	Fine-grain*	0·21	0·64	0·37	10·4	19·6	1·4	5·1	3·9	5·2	0·026	>0·005	0·0003	,,
	Coarse-grain*	0·22	0·51	0·31	10·4	20·4	1·4	4·9	3·8	5·2	0·018	>0·005	0·0003	,,

* Taken from four test-bars of each grain-size (coarse = 2½–3½ mm., fine = $\ngtr$0·5 mm.)



1 *General arrangement of investment-cast test-piece cluster*

Table 1, were used for 28 re-melt heats, and analysis of representative samples of the castings showed that little change in composition had resulted from re-melting (Table 1).

Controlled casting temperatures were used, to produce pre-determined grain-sizes. All the bars cast at 1,340°C. showed an average grain-size not greater than 0·5 mm., as measured in the region of the gauge portion on the cast surface. A casting temperature of 1,380–1,400°C. gave specimens varying in average grain-size from approximately 1–3½ mm. From the latter series of bars, batches of two different grain-sizes were selected: (*a*) 1–2 mm., and (*b*) 2½–3½ mm.

Testing procedures

All the samples were tested in the as-cast condition, using the test-pieces illustrated in fig. 2.

Room-temperature tensile tests, carried out by the De Havilland Aircraft Co. Ltd., were made on a Denison testing machine.

Stress-rupture tests were made in the Birmingham laboratory of the Mond Nickel Co. Ltd., using machines classified as of medium sensitivity, in which the strain measurement is measured by a dial gauge, actuated by the fall of the loading-beam. The test procedure was in accordance with B.S. 1687 : 1950.

Rotating-bend fatigue tests, carried out by D. Napier & Son Ltd., were performed in Gill machines, in which stress is applied by cantilever loading. The speed of rotation was 3,000 r.p.m.

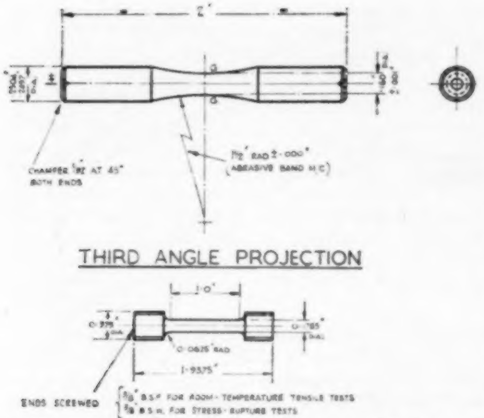
Tensile and fatigue tests were made on material from all the grain-size groups, but stress-rupture testing was confined to specimens representative of the extreme conditions of fine and coarse grain.

Experimental results

The test figures are listed in Tables 2–7 and are summarized graphically in figs. 3 and 4.

Consistency of properties within the various groups of tests was evaluated by statistical analysis of variance, and for the tensile results mean and standard deviation values have been calculated from 0·1% proof stress and for ultimate tensile strength.

For the stress-rupture and fatigue test results at each temperature a linear relationship between stress and log. life has been assumed. On this basis the line has been calculated for regression of



2 *Test-piece for room temperature tensile and fatigue and stress-rupture tests*

TABLE 2 *Room-temperature tensile tests*

Grain-size	0·1% proof stress ton/sq.in.	U.T.S. ton/sq.in.	Elong. %	R. of A. %
≯0·5 mm. (' Fine ' grain)	48·0	59·0	8	10
	49·4	59·2	6	9
	48·8	56·8	5	10
	48·4	55·4	5	9
	50·4	57·5	6	10
	51·4	55·9	4	10
	49·1	53·1	3	9
	50·2	59·4	8	9
Mean	49·4	57·0	6	10
Standard deviation	1·14	2·19		
1–2 mm. (' Medium ' grain)	45·6	54·5	6	9
	45·6	55·1	7	9
	47·6	54·0	5	9
	47·0	54·0	4	14
	48·7	62·2	10	14
	46·9	55·3	9	10
	49·3	60·4	6	9
	49·0	59·2	6	14
Mean	47·4	56·8	7	11
Standard deviation	1·47	3·26		
2½–3½ mm. (' Coarse ' grain)	48·3	53·8	6	10
	48·2	54·1	5	10
	49·4	53·8	5	9
	49·9	56·7	11	10
	48·0	55·6	8	14
	48·8	56·3	5	9
	49·1	55·2	5	10
	48·4	53·9	5	10
Mean	48·9	54·8	6	10
Standard deviation	0·66	1·17		

stress on log. time, and from this the standard deviation of the experimental values has been estimated in terms of stress.

Room-temperature tensile tests

The values obtained for the 0·1% proof stress, ultimate tensile stress, elongation and reduction of area (Table 2) show that grain-size, within the range studied, has little effect on room-temperature tensile strength and ductility. The small value of standard deviation shown by the coarse-grain material is noteworthy.

Stress-rupture tests

As with the tensile tests, variation in grain-size, in the range studied, have only slight effects on rupture strength. Tables 3 and 4 and fig. 3 show that at 980°C. the best lives were obtained with the largest grain-size, whereas at 870°C. the largest grain-size is superior only up to about 150 hours' life: beyond this, fine grain-size is preferable. The results at 750°C. show little effect of grain-size within the range of the experiments. At all three test temperatures the fine-grained samples show somewhat smaller standard deviation values than those of coarser grain, and, in each grain-size group, standard deviation becomes progressively smaller with rising temperature.

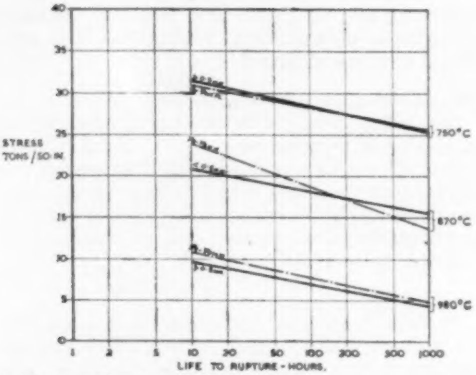
Fatigue tests

The results obtained in the cantilever, rotating-bend fatigue tests (Tables 3–5 and fig. 3) show that the influence of grain-size on mean fatigue strength

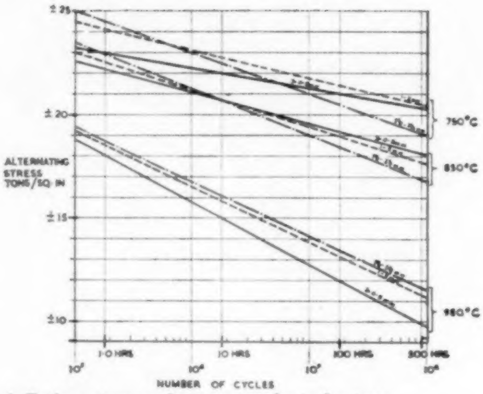
TABLE 3 *Stress-rupture tests on specimens of ≯0·5 mm. grain-size*

Stress ton/sq.in.	Temp. °C.	Minimum (secondary) creep rate % strain/h.	Life to rupture hours	Elong. at fracture %	Standard deviation, ton/sq.in. for rupture life
25·5	750	0·0018	502·7	1·9	1·29
26·0	,,	0·0019	437·3	1·8	
27·0	,,	0·0106	95·2	1·9	
27·5	,,	0·0079	106·6	0·8	
29·0	,,	0·0048	196·6	1·6	
29·0	,,	n.d.	92·3	1·1	
30·0	,,	0·0191	53·3	1·6	
31·0	,,	n.d.	11·6	1·3	
16·5	870	0·0131	189·5	5·2	0·92
17·0	,,	0·0083	585·5	7·3	
17·5	,,	0·0194	103·0	3·9	
18·0	,,	0·0445	78·3	5·1	
19·0	,,	0·0246	66·4	3·4	
20·0	,,	0·067	27·3	2·8	
5·0	980	0·0077	464·7	n.d.	0·69
6·0	,,	0·016	230·6	10·2	
6·5	,,	0·0255	138·8	6·5	
7·0	,,	0·018	111·5	7·1	
8·0	,,	n.d.	32·0	9·0	

n.d. = not determined



3 *Stress against mean life to rupture*



4 *Fatigue stress against mean cycles to fracture*

is small. At the two lower temperatures the fine- and medium-grain sizes are advantageous throughout test periods of 1–500 hours. The standard deviation values are in all cases smallest for the fine grain-size.

Discussion of results

An interesting feature of the room-temperature tensile tests is the small standard deviation obtained, for both proof stress and ultimate tensile strength, on the coarse-grain specimens. It might have been expected that the closest consistency would be shown by the fine-grain bars, but the results suggest that some other factor is involved. In this connection it is noteworthy that in the specimens used in these tests grain-size had been controlled by variation in pouring temperature and it seems likely that the low pouring temperature used in producing fine-grain castings resulted in a small amount of micro-porosity. The high levels of tensile strength and ductility indicate that the porosity was only slight, but it could be expected to increase the variability of these properties.

The stress-rupture results show substantially the expected effect of grain-size variation, *viz*., that at high temperatures a coarse grain confers maximum creep-resistance. Of particular interest is the effect of grain-size on the slope of the stress/log. time relationship at the intermediate temperature of 870°C. (fig. 3), indicating that although a coarse

TABLE 4 *Stress-rupture tests on specimens of 2½–3½ mm. grain-size*

Stress ton/sq.in.	Temp. °C.	Minimum (secondary) creep rate %strain/h.	Life to rupture hours	Elong. at fracture %	Standard deviation, ton/sq.in. for rupture life
25·0	750	0·0014	813·2	n.d.	1·38
26·0	,,	0·0016	403·3	1·4	
26·5	,,	0·002	460·5	2·5	
27·0	,,	n.d.	64·9	1·3	
28·0	,,	0·0162	173·1	1·6	
29·0	,,	0·0078	121·8	1·9	
30·0	,,	n.d.	37·3	1·2	
15·0	870	0·0036	412·4	4·3	1·3
16·0	,,	0·0052	329·8	4·9	
17·0	,,	0·0084	243·2	6·1	
19·0	,,	0·0197	108·1	5·0	
20·0	,,	0·0245	72·3	4·3	
21·0	,,	n.d.	23·1	2·1	
5·0	980	0·0013	953·6	n.d.	0·98
6·0	,,	0·0028	395·8	n.d.	
7·0	,,	0·0163	169·6	4·2	
8·0	,,	0·0182	73·0	4·4	
9·0	,,	n.d.	44·0	5·6	

n.d. = not determined

TABLE 5 *Fatigue results on specimens of* ≯0·5 *mm. grain-size*

750°C.		870°C.		980°C.	
Stress, ton/sq. in.	Cycles to fracture, × 10^{-6}	Stress, ton/sq. in.	Cycles to fracture, × 10^{-6}	Stress, ton/sq. in.	Cycles to fracture, × 10^{-6}
±25	0·1787	±24	0·0136	±18	0·2451
±24	0·0459	±23	0·0315	±17	0·1637
±24	0·2001	±23	0·6053	±16	5·1710
±23	0·0948	±22	3·1363	±15	5·2177
±23	3·0290	±21	0·3330	±14	8·1000
±23	8·8380	±21	0·6843	±13	3·9254
±22	0·0831	±20	0·9855	±13	16·0505
±22	0·0885	±20	3·0956	±12	32·6506
±22	0·2551	±20	18·2490	±11	23·2576
±22	54·0071	±19	1·2432	±11	30·4635
±22	68·7678	±19	28·4670	±11	32·7991
±21	0·4129	±19	38·4009	±10	9·0667
±21	26·8230	±18	75·3667	±10	29·1388
±20	100·0000	±18	102·2578		
±20	100·0920	±17	100·0402		
±19	102·4524	±17	128·5029		
±18	106·3303				
Standard deviation = 1·41 ton/sq. in.		Standard deviation = 1·16 ton/sq. in.		Standard deviation = 2·01 ton/sq.in.	

grain-size is superior for short-time service, a fine grain-size is better over longer periods. A corresponding effect at temperatures between 800 and 900°C. has been observed in other work on Nimocast 258 of relatively coarse grain-size, being demonstrated by a steeper slope of the stress/log. time relationship, compared with that shown by tests at temperatures outside that range. Results of the tests now reported imply that within a limited temperature range structural changes occur during testing, such that fine grain-size material conforms more closely than coarse-grain specimens to the rupture-behaviour pattern at other temperatures.

In all cases the consistency of the stress-rupture results is best for the fine-grain material, and this finding must be reconciled with the opposite effect shown by the room-temperature tensile results. It is suggested that under high-temperature stress-rupture conditions, the effect of the supposed trace of microporosity in the fine-grained material is swamped by other factors, arising from the influence of the grain boundaries on the processes of creep and fracture initiation. Since with the small specimens used the coarse-grain specimens had only a few grains to the cross-section, it might be expected that variations of grain boundary orientation, for example, would lead to greater variability in stress-rupture life in the specimens of larger grain-size.

An additional feature, which is of practical significance, is that the standard deviation values, expressed as a proportion of the mean stress levels, are minimum at the lowest test temperature for both fine- and coarse-grain material. This is possibly associated with the relative extent of the tertiary stage of creep, which is proportionately smaller at the lower temperatures. Moreover, variability in testing procedure should be at a minimum at low temperatures and high stresses.

The fatigue results are in good agreement with those of the stress-rupture tests, and show even more clearly the difference in optimum grain-size in relation to temperatures.

Conclusions

In this study of a creep-resistant casting alloy, Nimocast 258, it has been shown that the grain-size of investment-cast test bars can be varied by control of the pouring temperature. The variation of strength at room and elevated temperatures, over the range of grain-sizes studied, is small, and provides reassuring evidence that the degree of variation in grain-size occurring in commercial investment castings of moderate section thickness is unlikely to affect their mechanical properties appreciably. When the grain-size is small there is a tendency towards improved strength over extended periods at 750 and 870°C., but the potential advantage may not justify the risk of unsoundness associated with the use of a low pouring temperature in order to obtain fine-grain castings. Clearly, other factors also require consideration, *e.g.* the possible effects of grain-size on resistance to thermal fatigue, and alternative means of refining grain-size without risk of unsoundness may also be worthy of study.

Acknowledgments

The authors thank the De Havilland Aircraft Co. Ltd., who vacuum-cast the test-pieces and carried out room-temperature tensile tests, and D. Napier & Son Ltd., who made the fatigue tests.

They also acknowledge their indebtedness to the Mond Nickel Co. Ltd. for permission to publish this paper.

Table 6 *Fatigue tests on specimens of 1–2 mm. grain-size*

750°C.		870°C.		980°C.	
Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$	Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$	Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$
±27	0·0424	±24	0·0327	±18	0·1717
±25	0·0339	±23	7·8348	±16	1·7776
±24	1·0336	±22	1·3285	±15	11·9918
±23	0·0611	±21	0·1030	±14	16·4260
±23	0·1265	±21	1·4797	±13	17·9511
±23	3·2843	±20	15·8561	±12	35·1680
±22	7·6056	±19	14·1965	±11	43·0861
±21	27·4077	±18	41·7368	±11	107·0608
±20	100·0192	±17	49·0925		
		±16	109·9666		
Standard deviation = 1·39 ton/sq. in.		Standard deviation = 1·79 ton/sq. in.		Standard deviation = 1·39 ton/sq. in.	

Table 7 *Fatigue tests on specimens of 2½–3½ mm. grain-size*

750°C.		870°C.		980°C.	
Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$	Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$	Stress, ton/sq. in.	Cycles to fracture, $\times 10^{-6}$
±26	0·3552	±23	0·2097	±20	0·0915
±24	0·6038	±21	0·3632	±19	0·0262
±23	0·2004	±20	18·2426	±19	0·0293
±21	1·4308	±20	18·6282	±18	1·4343
±20	38·2891	±19	16·3008	±17	5·2421
±20	93·0931	±19	51·4319	±17	5·7298
±19	110·1739	±18	7·5550	±15	6·4850
±18	101·2009	±17	104·5279	±15	35·5830
		±16	105·9834	±13	20·6849
		±14	101·7041	±12	45·7447
				±11	99·7563
				±10	101·9847
				± 8	100·3122
Standard deviation = 1·73 ton/sq. in.		Standard deviation = 1·73 ton/sq. in.		Standard deviation = 2·2 ton/sq. in.	

Heat treating brass and copper tube

THE LATEST OF A SERIES of three similar electric roller-hearth furnaces to be supplied to Yorkshire Imperial Metals Ltd., Leeds, in their re-equipment and expansion programme, is now in operation. Designed and installed by G.W.B. Furnaces Ltd., the application of the furnace is the bright annealing of copper and annealing most analyses of brass tubes in straight lengths and copper tube in coils. Tubes in straight lengths up to 35 ft., from ½ in. o.d. by 20 s.w.g. to 4 in. o.d. by ¼ in. thick, and coils 5 ft. 9 in. o.d. by 6 in. high, weighing 150 lb. may be treated. By using extensions, conical tanker tubes 80 ft. in length have been treated. When annealing straight tubes the following outputs have been obtained:

Copper housing tube: ½ in. o.d. by 20 s.w.g., 2·85 ton/h.

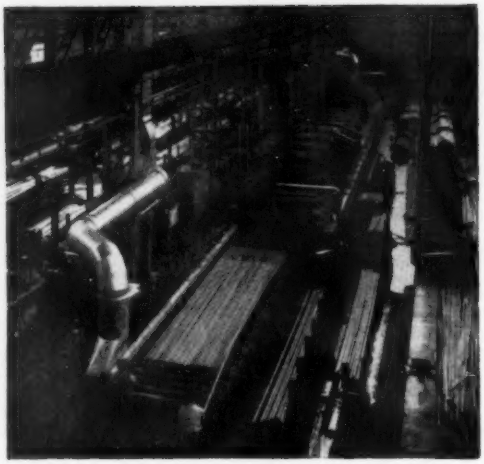
Brass tank heater tubing: 1½ in. o.d. by 14 s.w.g., 2·87 ton/h.

The equipment has an electrical rating of 550 kW. arranged in four automatically-controlled zones. Feed is from the 3-phase mains supply, distributed equally across the phases; the heating elements in each zone are fed through tapped transformers to give reduced ratings when working in the lower temperature ranges and when treating relatively light charges. The transformers supplying the zones give four values of reduced rating.

The heating chamber is 25 ft. long and can accommodate charges up to 9 in. in height and 6 ft. 6 in. wide. A water-jacketed cooling chamber 50 ft. long is fitted at the exit end of the heating zone and discharge vestibule so that the charge may be cooled gradually. To obtain the correct degree of heat balance from one end of the unit to the other and to provide a gas seal when feeding coils an entry zone 13 ft. 6 in. long is provided. The internal construction of these zones and also the inclusion of asbestos atmosphere baffle flaps give adequate sealing, thus reducing protective atmosphere losses when this form of charge protection is employed.

Heating derives from heavy nickel-chromium strip elements arranged in the roof and hearth. The heating elements in the roof are supported by nickel-chromium suspension hooks and those in the hearth by special refractory bricks.

Throughout the 166 ft. 6 in. of the installation the rollers are all power driven. All rollers are 4½ in. o.d. and flanged for locating the charge; those in the heating and cooling chambers are of heat-resisting alloy, whilst the remainder are mild steel. Rollers on the loading and unloading tables, together with those in the furnace vestibule, are set at a wider pitch than those in the heating and cooling chambers where maximum support of the charge at elevated temperatures is required. Again, to cut down atmosphere losses a section of high-speed charging rollers is arranged on the loading table and the first portion of the entrance chamber.



Front view of the 166-ft. G.W.B. roller-hearth furnace

Auxiliary equipment

A G.W.B. burnt town's gas plant has been installed for use when protective atmosphere annealing is required. Air and gas are mixed by a Selas air/gas mixer, the proportions being adjustable to obtain the correct CO/CO_2 ratio suitable for the metal being processed. The mixture is ignited in combustion chambers lined with refractory material and water cooled. The gases then pass through two scrubbers where cooling takes place and tar particles are removed by means of water spraying on to small coke. Before being fed to the furnace, sulphur is extracted from the atmosphere in two purifiers containing bog iron ore and activated carbon.

The heat treatment of a large range of tubes calls for a high degree of temperature control and this is provided automatically by means of a G.W.B. control cubicle. Four Kent Multelec indicating controllers are fitted, one for each zone, and a 4-point recording instrument allows a visual check to be made during any part of the process cycle. In the event of accidental overheating, safety contacts fitted to the 4-point recording instrument would cut off the supply to the heating elements.

Application of electron microscopy

Phase analysis of austenitic-ferritic welded joints

IVAN HRIVNAK

In recent years, at the Welding Research Institute in Bratislava, solutions have been sought to the problem of welded joints between austenitic and ferritic steels. This work is a contribution to research into welded joints between 17/7 *Mn-Cr austenitic steel (Czechoslovak standard CSN* 417481) *and ferritic steel Lof special extra. It was first reported in 'Zvaranie,'* 1959, *No.* 9. *The author is at the Welding Research Institute in Bratislava. The editorial reader was Dr. P. Rys*

FOR THE STUDY of transition layers between austenite and ferrite use was made of specimens of welded joints produced by resistance welding and argon arc welding. For the metallographic and electron microscope research the ground surfaces of the specimens were electrolytically polished in an electrolyte consisting of $CH_3COOH + HClO_4 + H_2O$.

Revelation of the structure of joints between two different materials creates distinct difficulties. If, for instance, an etchant is used which is suitable for the ferritic material, the structure of the austenite will not be revealed, and vice versa, if the etchant $HCl + HNO_3$ + picric acid, which is suitable for 17/7 Mn-Cr steel, is used for instance, there will be proportionately very little of the internal structure of the steel on the etch pattern obtained on the ferritic material. Therefore it was essential to find some method of revealing the structure which would be simultaneously suitable for both materials. It was established that electrolytic etching in a 10% solution of HCl (A.R.) in alcohol at a voltage of 6 V., with a distance between the anode and cathode of not less than 1 cm., using positive polarity, provided there is intensive stirring, is a suitable method of revealing all the structures of a duplex joint during exposure for a few seconds.

For research with the electron microscope use was made of negative collodion replicas shadowed with chromium, and of carbon extraction replicas, which were likewise shadowed with chromium to bring out the contrast (fig. 2). For this research work use was made of a Tesla BS-242 prototype electron microscope.

The microhardness values were measured on a Zeiss-Neophot microscope, working on the Hanemann system, with a loading of 50 g.

Research was carried out on specimens of 32 mm. dia. tubes with a wall thickness of 5 mm., either resistance welded on a welding machine or argon arc welded with added Mn-Cr, Mo, Nb material. The compositions of the 17/7 Mn-Cr, Ti material, the Lof special extra material and of the Mn-Cr, Mo, Nb weld metal are shown in Table 1.

After welding all the specimens were homogenized at 1,000°C. for 30 min. and cooled in air, and then tempered at 700°C. for 30 min. and cooled in air.

TABLE 1 *Compositions of the research materials, %*

	C	Mn	Si	P	S	Cr	Ni	Ti	Mo	Al	Nb	V
Base metal, 17/7 Mn-Cr, Ti	0·09	17·5	0·62	trace	0·025	7·4	trace	0·36	*	*	*	*
Base metal, Lof special extra	0·15	0·48	0·25	0·013	0·016	0·5	*	*	0·95	*	*	0·26
Weld metal, Mn-Cr, Mo, Nb	0·07	17·9	0·92	trace	0·02	7·38	trace	*	0·52	0·11	1·98	*

* Not determined

Metallography of 17/7 Mn-Cr and Lof special extra steels

The structure of 17/7 Mn-Cr austenitic steels is purely austenitic according to the equilibrium diagrams, but within it there can exist localized areas of intermediate ε and σ phases.[1, 2] Apart from this, these steels can contain carbides and a certain quantity of α-phase. The ε-phase has a hexagonal lattice with the parameters $a = 2 \cdot 536$ and $c/a = 1 \cdot 612$, and at higher temperatures, approximately from over 170 and up to 350°C., transforms into the γ-phase. The proportion of ε-phase in the structure at normal temperatures can be extremely high ($\simeq$ up to 75%), and its existence is continuous. A far greater influence on the drop in the mechanical property values of the material, however, is possessed by the σ-phase, which arises as a result of long-term heating in the range of higher temperatures around 800°C. The identification of trace phases in these materials is exceptionally difficult, and complex methods must be used to do so.

The structure of Lof special extra steel is dependent on the preceding heat treatment, and as structural components coexistent with the ferrite there may be normal or degenerated molybdenum pearlite, and at the same time complex carbides of the cementite and non-cementite types.

Experimental section

The purpose of this contribution is to assess the structure of the transition from the austenitic material to the ferrite. From diagrams of the isothermal and anisothermal breakdown of austenite, such as from the classic Dejean transformation-cooling rate diagram, it follows that between austenite and ferrite there are a series of transitional transformations such as troostite, bainite and finally martensite. Austenite may be regarded as a distinct supercooled state, brought about by an extreme cooling rate. It is true that this rate may be moderated to a reasonable extent by the addition of some alloying element, manganese for instance. From this point of view two instances of the transition from austenite to ferrite could occur:

(A) If we assume that there is no diffusion in both directions, then the transition structure on the side of the ferritic material will be the result of the relationship between this material and the cooling rate at any given moment, and can be martensitic, troostitic, variously modified, or ferritic.

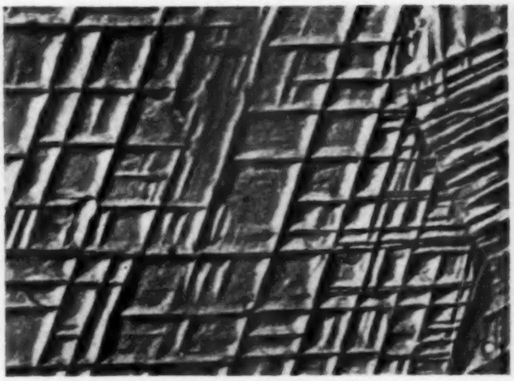
(B) If we assume that there is diffusion of the austenite-forming elements, of manganese for instance, into the ferrite, and on the other hand diffusion of carbon from the ferritic material, through the influence of local enrichment in alloying elements on the side of the ferrite, and also through the relatively high content of carbon, an austenite-ferrite transition zone can also be formed as bainite, as distinct from the structures on the boundaries.

Since two-sided heterogeneous diffusion must be assumed to occur in the instance where no diffusion barrier has been used, it will be extremely probable that the austenite-ferrite transition structure will be formed as bainite with alloyed carbides of the cementite type in the instance where the cooling rate is favourable.

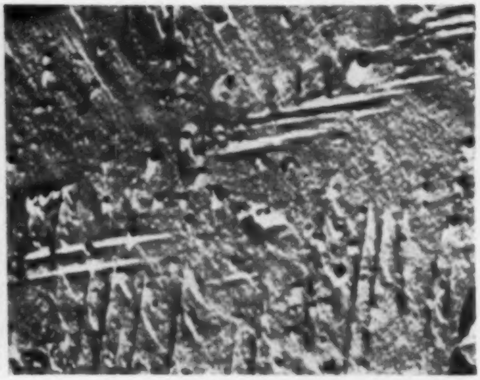
It is known that joints between austenite and ferrite are in service even in the range of higher temperatures up to about 550°C. If optimum conditions are obtained, *i.e.* if there is a bainitic structure of the transition zone, then as the diffusion of carbon progresses, it is probable that the width of the transition zone will be increased through the precipitation of carbides. At the same time, through the influence of the effect of heat, coagulation of the bainitically precipitated carbides will start, which will have a favourable influence on the reduction in hardness of the intermediate layer. Impoverishment of the austinite in alloying elements in the immediate vicinity of the transition zone, on the one hand through the diffusion of these elements into the ferrite, and on the other hand through their consumption by the precipitation of carbides which are formed by the continuous diffusion of carbon from the ferrite, will at the same time have an unfavourable effect on the mechanical properties of this zone. It is therefore necessary on these grounds to come to the conclusion that austenitic-ferritic welds without an intermediate layer, *i.e.* without a diffusion barrier of nickel for instance, will not have the required properties in service at higher temperatures, either through the use of a ferritic material with a low carbon content, or in the instance where the values of the joint after welding were satisfactory before being put into service at higher temperatures.

There also exists one further possibility, and this is to choose such a method of welding, resistance welding for instance, that the hard intermediate layer formed has a suitable orientation, *i.e.* at right angles to the axis of the tube, in relation to the direction of stressing, and that its width shall in general be not greater than 1 micron, for instance, so that in it only biaxial states of stress shall be brought to bear. Such joints would certainly have good properties before being put into service,[3] but in consequence of the facts presented above, without doubt their properties would continuously worsen in service.

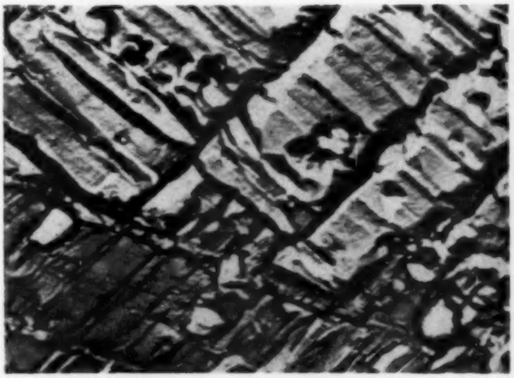
In a joint work[4] the author studied the diffusion conditions in a duplex, austenitic-ferritic joint between 16 Cr-13 Ni type and high-carbon steels during long-term heating in the range of elevated temperatures, and established that the variable



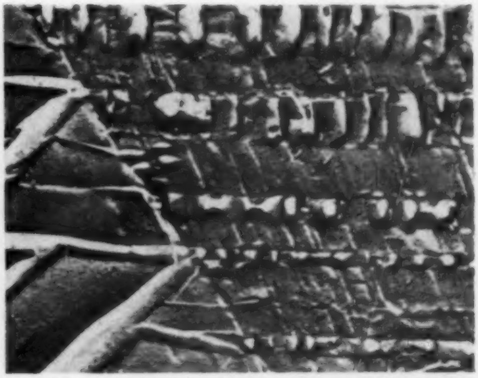
1 *Structure of 17/7 Mn-Cr, Ti austenite* × 10,000



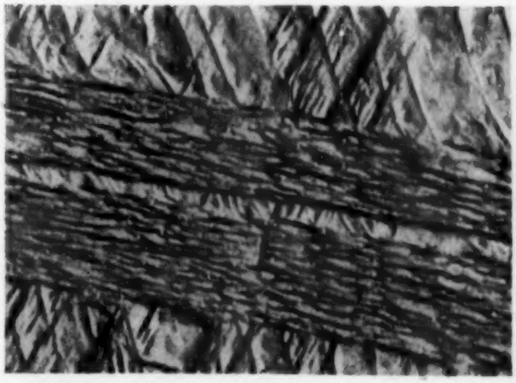
2 *Precipitation of carbides in the heat-affected zone* × 10,000



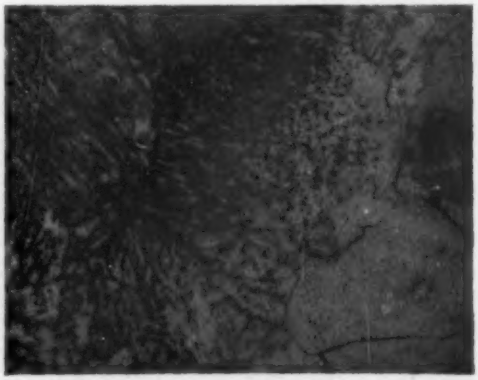
3 *Dendritic orientation of the weld metal* × 10,000



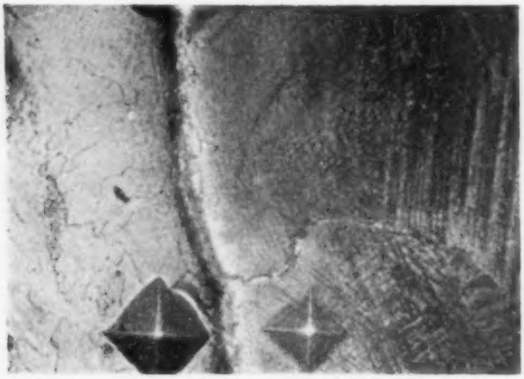
4 *Initiation of precipitation of ε-phase and its morphological multiplicity* × 10,000



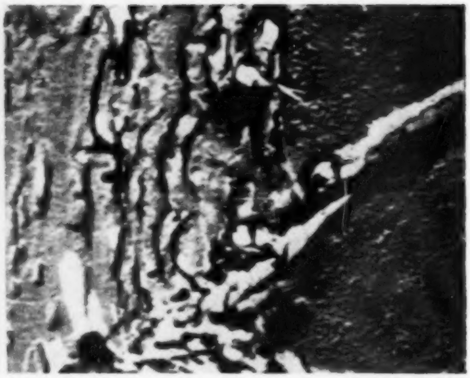
5 *Modified orientation of the weld metal* × 10,000



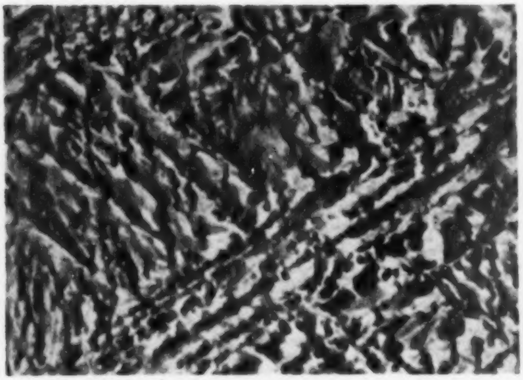
6 *Transition to the intermediate layer during resistance welding* × 1,000



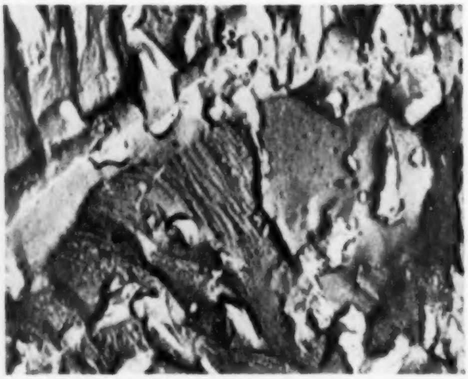
7 *Transition to the intermediate zone during arc welding* × 1,000



9 *Detail of the transition zone* × 10,000

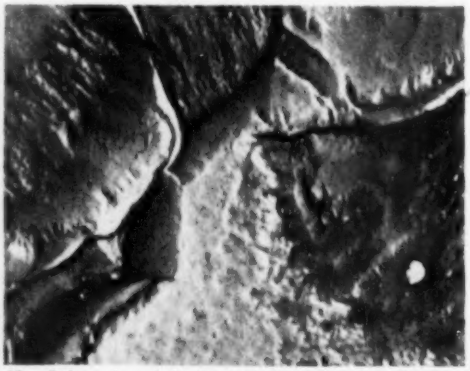


10 *Morphology of the bainitic intermediate layer* × 10,000

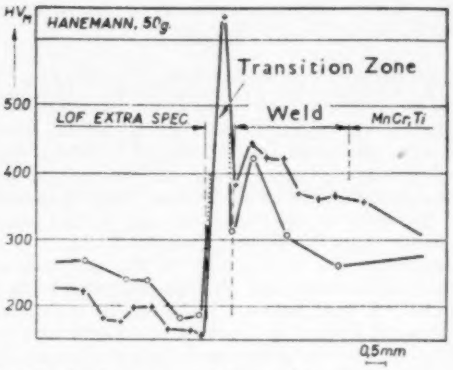


11 *Area of ferrite with intense carbide precipitation* × 10,000

12 *Termination of the diffusion boundary* × 10,000



13 *Orientation of the ferrite in the heat-affected zone* × 10,000



8 *Microhardness curves of the transition zones*

diffusion of carbon into the austenite is extremely intense, and ends at a considerable distance from the joint in an area of intensive precipitation of chromium carbides along the boundaries of the austenitic grain and the mosaic block structures.

In this study it has proved possible to establish the morphology of the transition zone and the width of the diffusion, and from these values to assess the quality of joints produced by arc and resistance welding.

As has already been stated in the general observations above, joints were made between type 17/7 Mn-Cr steel and ferritic Lof special extra steel in the quenched and tempered state, having a ferritic structure with finely dispersed carbides. The structure of Mn-Cr austenitic steel contains a large quantity of ε-phase with a regular structure. Its morphological configuration is characterized by fig. 1, from which it is evident that contact between the ε-phase and the grain boundary initiates the formation of this phase in another grain. In the structure of the austenite it is also possible to identify a small quantity of carbides, whose dimensions do not attain 1 micron. In both instances of welding, arc and resistance, the heat-affected zones of the Mn-Cr materials were similar: after homogenizing and tempering heat treatments, however, through the influence of the thermal and energy shocks which occur, intensive precipitation of carbides takes place at the expense of a decrease in the presence of the ε-phase, as is shown by fig. 2.

There is a fundamental difference between the orientations of the weld metal produced by arc and resistance welding. During arc welding with the use of Mn-Cr, Mo, Nb wire in a protective atmosphere of argon, the weld metal has a pronounced dendritic orientation, whereby the precipitated ε-phase is also arranged in variously modified, bizarre formations. Once again we have a texture (fig. 3) which is oriented in the direction of the maximum extraction of heat. It is interesting that the effect of the initiation of the ε-phase on the grain boundaries is in this instance also extremely pronounced, and indeed the newly-forming ε-phase possesses very nearly the same direction as that of the original orientation (fig. 4). The chance existence of further intermediate phases could not be unambiguously identified from the profusion of formations. It is probable that the great multiplicity of the structures of this orientation is likewise governed by the content of molybdenum, niobium and aluminium.

This fact is especially noticeable from a comparison of the weld metal from the metal added during arc welding with the weld metal from the melted base metal in resistance-welded joints between these steels. The structure of the weld metal in the latter instance does not have the marked dendritic structure but only slight traces of it, while the precipitation of the independent ε-phase is likewise modified, as is shown from the close proximity of the transition zone in fig. 5.

The structure of the transition zone between the austenite and ferrite produced by the two welding methods confirmed the hypothetical considerations which were presented at the beginning. The transition zone is bainitic; this results from diffusion from the side of the austenite and also precipitation of carbides along the grain boundaries, thereby causing local impoverishment in carbon on the side of the ferrite. A qualitative distinction between the two methods of welding was not determined; the width of the intermediate layer, however, is greater in the instance of arc welding (fig. 6), whereas during resistance welding it attains only a few microns (fig. 7). In both instances relatively high hardness of the intermediate layer was established, which contrasts strongly with the level of hardness in its vicinity. For comparison, in fig. 8 is shown a diagram of the micro-hardness curves of the transition zones for both welding methods. Through the effect of the impoverishment in carbon, the hardness of the heat-affected zone of the ferrite falls, while through the influence of the zonal diffusion of carbon into the austenite and the precipitation of carbides the hardness on the austenitic side of the transition zone is increased. Within the limits of this work it is impossible to discuss the change in the hardness curves during a prolonged period of exposure in the range of operational temperatures.

The morphology of the intermediate layer, which structurally was formed originally as low-temperature bainite, but has become partially spheroidized through the effect of the further heat treatment, is characterized for arc-welded joints by fig. 9, with a distinct typical orientation, while for resistance-

welded joints, as fig. 10 shows, the intermediate layer has a relatively softer structure, and its thickness does not exceed a few microns.

And since the width of the intermediate zone is in general less during resistance welding, the transition to ferrite is all the more abrupt than the transition during arc welding. In the latter instance the bainitic zone is extended by the intensive precipitation of coarse carbides of the cementite type and of finely dispersed carbides, especially on the boundaries of the ferritic grains.

Fig. 11 is characteristic of this zone. Further towards the ferrite the quantity of cementite carbides falls, but within the ferrite precipitation proceeds continuously through the effect of diffusion of the alloying elements, especially chromium; evidence of this is provided by fig. 12, which shows these areas. It is known that manganese promotes a pearlitic reaction, and can be dissolved in cementite to a considerable level; it is therefore probable that this cementite has an increased manganese content through the effect of the diffusion. In areas still further removed from the transition zone impoverishment of the ferrite in carbon may be observed, and thereby a reduction in the quantity of carbides also. But the morphology of the ferrite is evidence of the action of kinetic energy shocks (fig. 13).

Conclusions

This work reviews problems of the transition between the different materials in duplex welds between austenitic and ferritic, 17/7 Mn-Cr type and Lof special extra steels. It was shown that through the influence of diffusion from both sides of the weld, in the transition zone a hard intermediate layer is formed, which is bainitic in character. The morphology of this intermediate layer was studied, and also the transition from it to the two base metals. It cannot be considered that joints formed in this way, since they have no diffusion barrier, would be satisfactory, especially during long-term service in the range of elevated temperatures.

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Coating niobium for high temperatures

NIOBIUM has all the essentials for a good base metal for the development of superior high-temperature alloys except for its poor oxidation resistance. Alloy additions confer some oxidation resistance, but only at the expense of high-temperature strength or of fabricability or both. It appears that unless and until some useful oxidation-resistant alloys are proved out, a parallel effort must be made to develop coatings for suitable alloys.

In addition to providing protection against oxidation, a useful coating must also have the quality of repairing (over the temperature range to be experienced by the coated object) any cracks or flaws initially present in the coating or which might be expected to form because of mechanical or thermal strain in service. The U.S. Naval Research Laboratory has developed a type coating to meet these two requirements, according to G. Sandoz, *J. Metals*, April, 1960.

In its simplest form this new coating consists of layers of intermetallic zinc-niobium compounds on the surface of the niobium. The intermetallics may be formed by applying zinc in any of several ways, the simplest of which is perhaps by dipping the niobium in molten zinc. Subsequently, the zinc is reacted with the niobium substrate in a diffusion-anneal in air in the general range of 870°C., a treatment which also causes layers of zinc oxide and zinc-niobium oxide to form on the surface.

As with most intermetallic compounds, the zinc-niobium intermediate phases are hard and brittle, and they are readily cracked either by mechanical strain or by thermal shock, but they are securely anchored to the niobium substrate and do not tend to spall, and in fact can be dislodged only with great difficulty.

Such a coating produced from unalloyed zinc and unalloyed niobium protects against influx of oxygen (as judged by micro-hardness traverses and bend ductility) for several hundreds of hours at 980°C. and for a few days to a few hours in the range 1,090–1,200°C. in still air.

Preliminary evaluation in hydrocarbon combustion products moving at 500 ft./sec. and with metal temperature of 1,090°C. showed no indication of oxygen absorption or other embrittlement in tests of 5-h. duration. (Uncoated control specimens are completely converted to oxide in about 3 h. at these temperatures.)

Perhaps the most strikingly successful aspect of the zinc-type coating is its self-healing ability. An opening in the coating to bare niobium is rapidly covered by a thin layer of oxides; zinc coming from the adjacent coating quickly re-forms the intermetallic layers.

Cold deformation of metals

Part 2—Cold extrusion

H. Ll. D. PUGH, B.Sc., F.Inst.P., F.I.M.

Studies to increase knowledge of the basic mechanics of deformation of metals have been carried out at the National Engineering Laboratory, East Kilbride, on forging and extrusion as well as on general deformation. A brief account of some of this work was given at the Tenth Technical Convention of the NADFS at Droitwich last November by the author, who is head of the Plasticity Division of the National Engineering Laboratory. The article is concluded this month, together with a summary of the resulting discussion at the convention

THE GROWTH of the extrusion of metals into a major commercial process is of more recent origin. Early studies of the process both in Germany and this country, which are described in Pearson's[13] book, did much to elucidate the flow of metals under different conditions and establish some empirical relations between certain variables governing the process.

Of recent years, theoretical work, particularly by Hill,[14] has led to a number of solutions for plane strain extrusion under various conditions. Whilst no solution for the axi-symmetrical problem has yet been produced, the plane strain solutions do give valuable information regarding extrusion pressures, die loads and deformation patterns. However, the detailed study of axi-symmetrical extrusion must still be carried out experimentally. Such a study was initiated by Professor H. W. Swift[15] at Sheffield and continued at NEL.

The extrusion process has been used for a considerable time to produce a diversity of small products, particularly containers of all types. Its attractive features are that it offers a high production rate, close dimensional control, and good appearance with economy of metal, enhanced properties of the material after deformation, and since this occurs under a predominantly compressive stress the chance of failure is smaller. The metal can be deformed in a hydraulic press or a mechanical press of the crank, knuckle, beaver tail, cam action or screw type.

Cold impact extrusion of steel

In industry, great advances have been made in production techniques since cold extrusion was first undertaken in the 1930s. It has largely developed as an intermediate or combined process incorporating other deformation processes such as upsetting, forging, etc. The production of steel components by cold extrusion has been retarded by the scarcity of basic information and it was to meet this need that work was started at NFL on axi-symmetrical shapes.

The tests were carried out in a variable speed (10–60 strokes/min.) 150-ton crank press capable of single stroke action. The crank shaft fitted with an eccentric adjustable collar and connecting rod gives a stroke varying from 3–12 in. A slide motor gives a 6-in. variation in daylight.

The stroke is measured by a cylindrical variable capacity gauge fixed between bottom platen and top ram platen. The load is recorded by a parallel-plate condenser gauge. Both are recorded together with a time marker on a C-R-O unit giving a complete film of load, stroke and time history of extrusion.

The punch is held to the ram platen by a punch holder. The extrusion sub-press consists of a separate chamber and die to permit a wide range of tool arrangements. The tooling could be arranged to produce rods, tubes or cans.

The effect on the extrusion process of variables: (*a*) extrusion rate, (*b*) ram speed, (*c*) lubrication,

(*d*) die geometry, and (*e*) slug length/diameter, has been studied for non-ferrous materials and various carbon and alloy steels to the following B.S. specifications:

En 1A (0·1% C)—free cutting steel.
En 2A (0·15% C)—cold forming steel.
En 3B (0·16% C, 0·76% Mn).
En 8 (0·42% C, 0·65% Mn).
En 9 (0·62% C, 1·16% Mn).
En 16 (0·35% C, 1·5% Mn, 0·25% Mo)—manganese-molybdenum steel.
En 33 (0·1% C, 3% Ni)—case-hardening steel.
En 42 (0·78% C)—spring steel.
En 44 (1·03% C)—spring steel.
En 40B (0·3% C, 3% Cr, 0·4% Mo)—nitriding steel.
En 54 (0·4% C, 14% Cr, 14% Ni)—valve steel.
En 58B (0·13% C, 19% Cr, 9% Ni)—austenitic chrome-nickel (stainless) steel.
Armco iron (0·03% C).

The slugs (1 in. dia.) were all annealed and well lubricated, having first a zinc phosphate treatment and then Bonderlube 235 (sodium stearate) or molybdenum disulphide was applied.

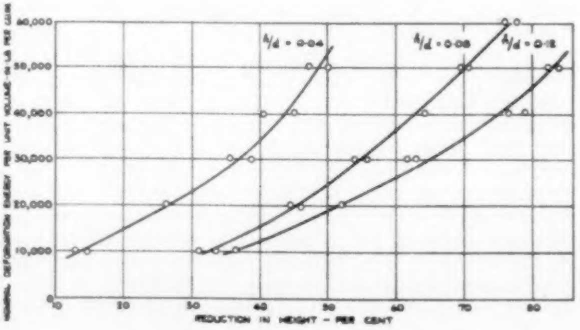
Fig. 10 shows the pressure/stroke characteristics for the extrusion of 0·6-in. dia. rod (extrusion ratio of 2·8) at 10 strokes/min. in various steels. After the initial peak the fall-off in extrusion pressure is very marked for the high carbon and alloy steels; indeed, at the end of the stroke En 44 is extruding at a lower pressure than Armco iron.

The results for the effect of reduction on the maximum extrusion pressure, press load and tool face pressure for the three typical products in En 2A is shown in fig. 11. This figure also indicates diagrammatically how the products are formed. The extrusion pressure (*i.e.* extrusion load/area of slug) is much the same for rod and tube, but is distinctly lower for cans. The stress on the forming tools (*i.e.* on the die face for rods and tubes, but on punch face for cans) is a minimum for an extrusion ratio of about 2. The minimum value for cans is lower than that for rods and tubes, probably due to friction. The occurrence of this minimum value is of great importance particularly in the case of cans because the stress on the punch limits the length/diameter ratio of the punch and hence the length of can that can be made from a solid slug. This operation is almost always the first operation in making a tubular product from solid bar.

With good lubrication the pilot size did not affect the maximum extrusion pressure, but the press load was lower the larger the pilot size due to the reduced cross-sectional area of slug. This feature enabled thin-walled tubes of 0·017-in. wall thickness and 1 in. dia. to be successfully extruded at an extrusion ratio of 12, the maximum extrusion pressure being 210 ton/sq. in.

The maximum extrusion pressure/reduction ratio relationships for the different materials are shown in fig. 12. The effect of increasing carbon content can be seen by noting the relative positions of the curves for Armco iron, En 1A (0·1% C), En 2A (0·15% C), En 2C (0·24% C), En 8 (0·42% C), En 42 (0·78% C) and En 44 (1·03% C). Their other main constituent is manganese which varies between 0·6 and 0·75%, and the extent of this variation can be assessed by comparing the curve for En 3B (0·76% Mn) with that for En 2A (0·63% Mn), both of which contain 0·15% C. From a comparison of En 6 (0·39% C, 0·82% Mn) with En 8 (0·42% C, 0·65% Mn) and En 9 (0·62% C, 1·16% Mn) with En 42 (0·78% C, 0·63% Mn) it would appear that carbon is about four times as effective as manganese in increasing the maximum extrusion pressure.

No difficulty was experienced in extruding the plain carbon and alloy steels and the products so obtained were satisfactory except those from steels En 54 and En 58B, which exhibited internal 'fish-tail' flaws. The effect of increasing extrusion ratio on the hardness of the extruded product is clearly seen from fig. 13. The mean hardnesses were assessed by means of traverses taken across the mid-section of axially split and polished pro-



9 *Deformation of thin cylindrical specimens of lead at a strain rate of 700 sec*$^{-1}$

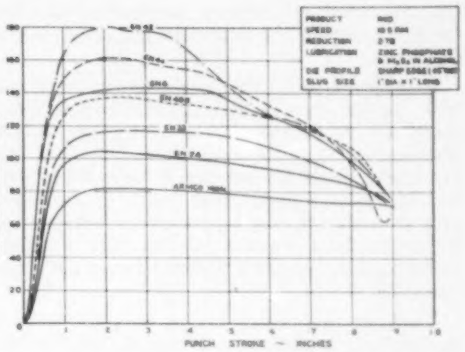
ducts. It will be noted that the mild steels harden proportionately more than the higher carbon and alloy steels and that at the higher reductions the hardness values achieved are equivalent to those obtained from low alloy steels in the fully heat-treated condition. This fact could have considerable economic significance.

Extrusion under pressure

The work described above contributes directly to existing commercial deformation processes. It is essential for the industrial health of the nation that a national laboratory should also look ahead and engage in long-term research. I propose now to briefly indicate some work of industrial interest which has arisen from such fundamental research.

Investigations are proceeding at NEL aimed at carrying out simple mechanical tests, *i.e.* tension and torsion, in the presence of a pressurized fluid on a range of metals in order to determine the stress/strain relations under such conditions. The object of the investigations is to study the behaviour of metals under conditions similar to those which exist in metal-forming processes. In such processes, *e.g.* extrusion, a large hydrostatic component of stress is produced and deformation takes place under these conditions.

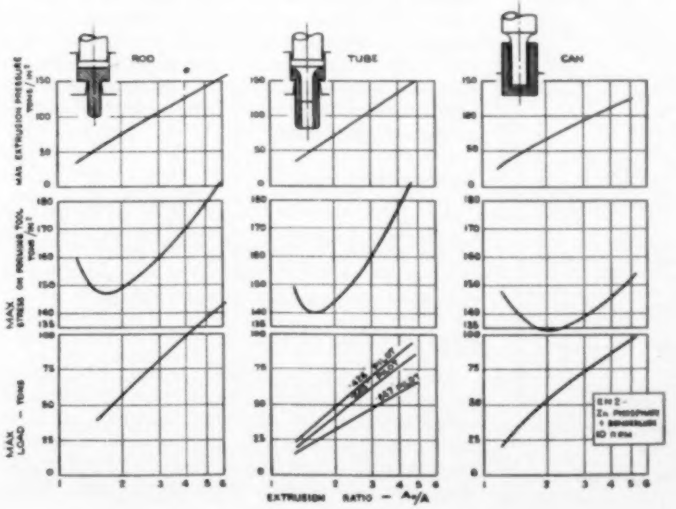
In order to obtain the fluid pressures required (up to 100 ton/sq. in.) a fairly substantial pressure chamber was required and a 450-ton hydraulic press was used to supply the loads. It was found in carrying out tension tests on various materials that as the pressure was increased, the area of fracture became progressively smaller, *i.e.* the ductility or the strain to fracture became progressively



10 *Extrusion pressure/stroke characteristics for various steels at an extrusion ratio of* 2·78

greater. This result is typical of all the metals tested, as seen from fig. 14, except that the transition from brittle to ductile behaviour occurs gradually in some cases, *e.g.* magnesium, and abruptly in others, *e.g.* zinc. In the case of zinc there is a fairly sharply defined critical pressure above which it is extremely ductile.

This fact of increasing ductility with increasing hydrostatic pressure really explains why forming processes are so successful in shaping metals without cracking. The design of dies, rolls, etc., are such as to build up a large hydrostatic component of stress in the material, which therefore shows a considerably enhanced ductility during deformation under these conditions. It is therefore not surprising that strains many times larger than the



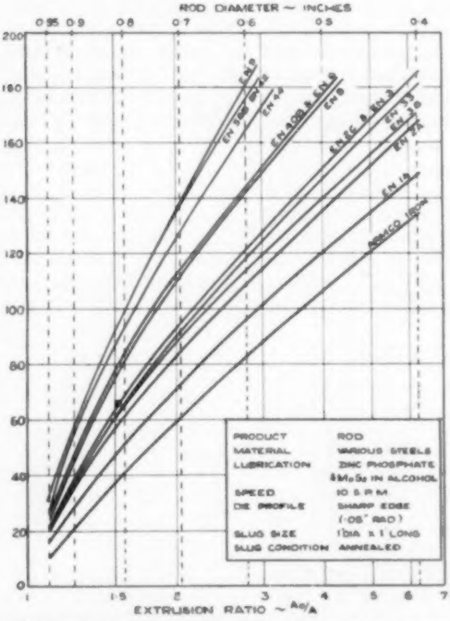
11 *Effect of reduction on extrusion pressure, load and tool face pressure*

fracture strain in ordinary mechanical tests can easily be obtained in formation processes such as extrusion.

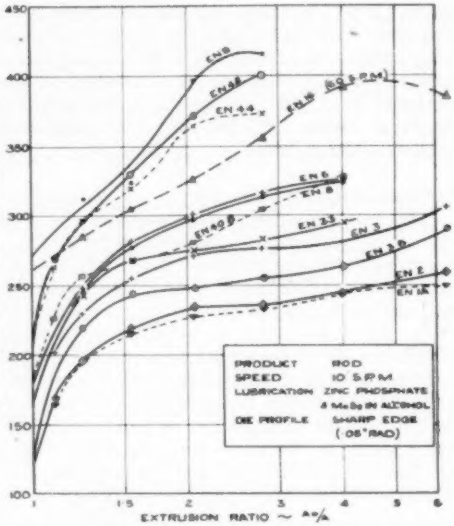
It occurred to us that if the above hypothesis were correct, then in the case of materials which could not be extruded satisfactorily, *i.e.* without cracking, at atmospheric pressure, a marked improvement could be expected if the process were carried out in a pressurized fluid. If successful, then it would not only be possible to obtain satisfactory extruded products but that these would be endowed with enhanced properties over the virgin materials.

Two materials which cannot be cold extruded satisfactorily at atmospheric pressure are bismuth and magnesium, and it was decided to try and cold extrude these in the high pressure chamber.

For tube extrusions the initial slugs, which were $\frac{3}{8}$ in. dia. with $\frac{1}{8}$ in. concentric bore, were extruded to tubes $\frac{1}{8}$ in. bore and various external diameters. A lubricant of molybdenum disulphide and lanolin was applied to the slug. Extrusions were carried out both at atmospheric pressure and under high pressure. During the extrusion under pressure the pressure increased, due to the fact that the top plunger used to seal off the pressure chamber was pushed down to extrude the slug.



12 *Effect of reduction on the maximum extrusion pressure required for various steel rods*



13 *Effect of reduction on the mean hardness of rods extruded from various steels*

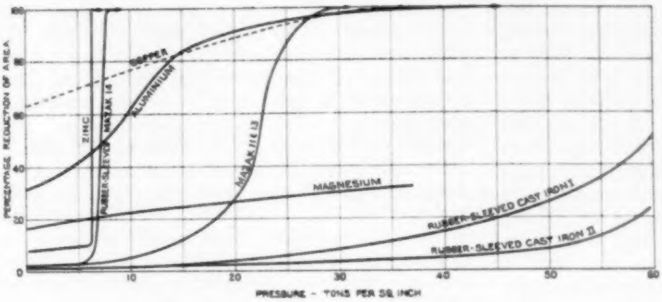
The results for bismuth for an extrusion ratio of 2·26 showed that at atmospheric pressure the extrusion is severely and deeply cracked on its outside surface, whilst that at a pressure varying from 17 to 35 ton/sq. in. has no visible cracks. Similar results were obtained with magnesium at an extrusion ratio of 3·16, where again the atmospheric pressure extrusion is badly cracked whilst that at high pressure is uncracked and has a good surface. The results for 60/40 brass show that the atmospheric pressure extrusion is a series of small fragments. The pressurized extrusion (ratio 3·9) is still badly cracked but is in one piece and is a considerable improvement on the normal extrusion. Higher fluid pressures would be required to produce an uncracked product.

Acknowledgments

The work described in this paper forms part of the research programme of the Plasticity Division of the National Engineering Laboratory, Department of Scientific and Industrial Research, and is published by permission of the Director.

DISCUSSION

Mr. A. W. Matthews (Gee, Morgan Ltd.) asked the author if he would comment on the effect of temperature in the extrusion operation and its effect on the reduction of maximum extrusion pressure, particularly in relation to En 42 and En 44. Were the two related, more temperature being



14 *Effect of pressure on percentage reduction of area for all materials tested*

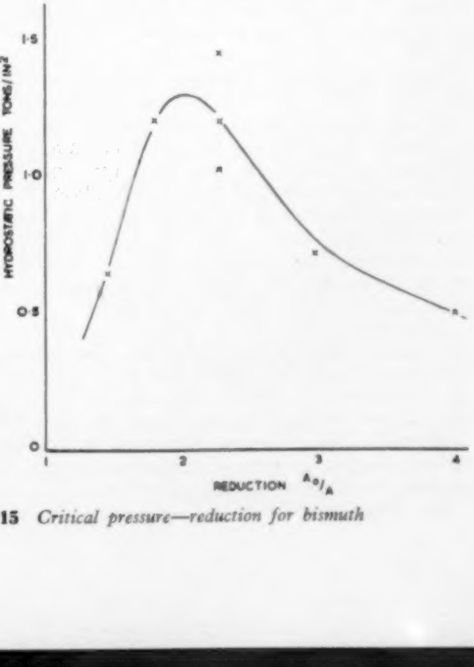
generated when extruding En 42 and En 44 than when extruding En 1A and En 2.

Mr. Pugh said that although they had not investigated this particular point in detail, he thought that the reason why that the extrusion pressure curve for En 44 dropped at the end of the stroke so that this steel was extruding finally at a lower pressure than that for Armco iron, was due to the fact that initially its extrusion pressure was higher, therefore the amount of work done was higher. All this work, by and large, was converted into heat and therefore the temperatures produced in the En 44 slug were higher than they were with an Armco iron. The effect of these higher temperatures was to bring down the effective yield stress of the En 44 in relation to the Armco iron.

The question of temperature was quite an important one, particularly in non-ferrous materials. Non-ferrous materials could be extruded under certain circumstances, in such a way that the temperatures developed in some cases made the term cold extrusion meaningless. One might, for instance, get in aluminium, temperature rises of up to 300°C. and in some cases these temperature rises might be sufficiently big to virtually wipe out the improvement in mechanical properties due to cold working. In other words, one was really 'warm working' the product and ending up with properties which were not as good as might have been expected from a cold-working process.

Mr. J. V. Scanlan (High Duty Alloys Ltd.) asked if in the investigations in which the aluminium tests were tensile tested at various pressures, there was a very marked effect on the tensile strength or on the ductility of the specimen as the pressure increased. Also in the use of pressurized extrusion, had this been attempted in hot extrusion of the more difficult materials, in which cracking was experienced. Mr. Scanlan mentioned Nimonics, magnesium and also aluminium which were limited on extrusion speeds by the cracking developing as the frictional speed increased.

Mr. Pugh said that they had only recently begun work on aluminium and had not yet actually measured tensile strengths of extruded products, but were in the process of doing so, and hoped to have some results in the not too distant future. He thought it possible that the stress/strain relation of a material was the same under pressure as it was at atmospheric pressure. The only difference was that by putting on hydrostatic pressure the stress/strain curve could be carried to much larger strains. Assuming a stress/strain relation for a material which could go on to infinite strain, then where this actually finished, *i.e.* where one actually got fracture, would depend on the environmental conditions. If it was atmospheric pressure, this maximum strain was relatively low. By arranging the pressure, or the environment to give large hydrostatic compressive stresses, this curve would continue to a much larger strain, but it was still the same curve. Therefore, in so far as larger strains could be obtained under hydrostatic pressure than at atmospheric pressure, a material capable of



15 *Critical pressure—reduction for bismuth*

sustaining higher true stresses, by deformation under pressure was obtainable. In other words, supposing the fracture strain for aluminium to be 5–10%, by straining the aluminium under hydrostatic pressure to say 40%, then a material would be obtained with a higher true tensile strength than the same material deformed at atmospheric pressure.

On the question of hot extrusion, Mr. Pugh said that they had not tried it, but were anxious to do so. In fact they were very glad of suggestions relating to industrial problems in order to try them out in the laboratory. They were in a position now to do tests at limited temperatures, under pressure, and he thought that tests at pressures of up to 70 or 80 ton/sq. in. fluid pressure at temperatures up to 400°C. could be attempted. In the immediate future they intended to try to cold extrude beryllium. Beryllium could not be extruded cold at atmospheric pressure, but they felt that because of the advantage of using a pressurized fluid that there would be distinct hope that a successful product could be obtained.

On the question of hydrostatic pressure-induced ductility, Mr. Pugh was asked whether this also applied when steel was formed by a high explosive placed in a liquid such as water.

Mr. Pugh said that he understood that the explosive forming described was done by immersing the material in liquid, say water, and the explosive detonated near it. If conditions were such that there was a pressure back and front of this material, in fact something approaching a hydrostatic stress, then he thought that enhanced ductility would result. He was reluctant to give a firm answer, not being sure how quickly the material deforms. It might, in fact, deform before pressure got round to the back of the plate for instance. Furthermore, he was not sure what advantages, if any, were inherent in explosive forming, this was another point on which they were particularly interested.

Mr. B. Grassam (E.S.C.) said that he had two questions. The first one concerned the graphs of extrusion pressures. He wondered what was the initial structure of the material, because there could be great differences in the initial hardness which would be a vital factor. Had Mr. Pugh attempted to bring them both initially to the same hardness or the same structure or the softest possible for each material which would be different?

The other point was, in considering enhancement of physical properties by cold deformation, were we starting with a fully treated piece, was there an enhancement of all the properties or was it at the expense of ductility, and were we sure we could utilize that enhancement or were the forgings likely to distort because of stresses set up and so require annealing to prevent distortion?

Mr. Pugh said he would start with the last question, *i.e.* the enhancement of properties by cold working. The answer was, of course, that what was gained on the swings was lost on the roundabouts, and particularly, as might be expected, improvement in yield strength or the mechanical properties in tension, say, would result in a loss of ductility. This bore out the point he had tried to make earlier that when working on the same stress/strain graph, by going further along there would be less ductility than would result by stopping lower down. Nevertheless, there would be areas of applications where such properties were required and one might be prepared to sacrifice a little ductility to get a higher strength. As far as the initial hardness of steels was concerned, the answer briefly was that they were taken in the annealed form and they were all of different hardness.

Mr. McKenzie (National Engineering Laboratory) also commented on the question of hardness, and said that in this case they were all annealed, but one of the points that was specially studied was the fact that the steels weren't in any way experimental steels. They were all steels that could be bought as rolled bar stock and all of them were metallurgically examined in the normalized condition or annealed condition; some of them had stringers and some segregations and some of them were badly segregated with things like manganese sulphide down the core. They all extruded irrespective of whether or not, as far as the metallurgist was concerned, they were bad materials. These hardnesses varied from about 100 V.P.N. if the material was very softly annealed for a carbon content from 0·1 to 0·15% up to about 250 or 260 V.P.N. with steels that had amounts of chromium and nickel in them.

There was a further point which an earlier question had raised about En 42 and En 44. The En 42 was a 0·78% carbon spring steel, and En 44 a 1% carbon spring steel. If one looked at the tensile test of various carbon content steels, it was found that there was a turning point at the eutectoid and that in actual fact an En 42 had a higher extrusion pressure and ultimate tensile strength than a En 44.

Mr. F. C. Bird (Walter Somers Ltd.) asked whether Mr. Pugh would comment upon the factor of viscous flow which had been rejected in order to reduce the number of variables. He felt that as more complex shapes were required, the viscous component might come into it.

Mr. Pugh said that he did not think the viscous resistance would be unduly more important in one type than in another. In fast metal-working processes, for instance explosive forming, then viscous resistance might well be very important, but in relatively slow cold tests he did not think it would be particularly significant.

Spark machining symposium

Metallurgical aspects and surface characteristics

PROF. DR.-ING. H. OPITZ

This article is the sixth of a series on spark machining and forms part of the symposium held last September in Birmingham by the NADFS *in collaboration with* METAL TREATMENT. *Prof. Opitz, Technische Hochschule, Aachen, discusses fundamental aspects of the relationship between the metallurgical changes in the work-piece and the mechanism of spark erosion*

THE RAPID DEVELOPMENT of processes for working metal by spark erosion becomes important when the large number of types of spark-erosion machines as well as the many different fields of application are considered.

As in the case of every new process, mainly empirical data are assembled chiefly regarding the possibilities of application, efficiency characteristics, operating instructions and economics while further developments are put on a solid basis.

This is so in general, and especially in the question to be studied here, of changes arising in the surface layers worked by spark erosion. It is not sufficient for the profitable adoption of the process merely to obtain the prescribed dimensional accuracy and depth of roughness. In addition to this, the amount of reliable work turned out and the resistance to wear of die-sinking or cutting dies worked by spark erosion must be assessed and the means of influencing them investigated.

With spark-erosion machines, which are generally alike as regards their working principles and basis circuit layout, it is necessary for this purpose to find a reference system which gives a connection between the results of the machine in operation and the adjustment values. For, in spite of similar components such as capacitors, resistors and inductances with similar electrical data, the results obtained may turn out to be very different. Investigation leads to the realization that here, in addition to the type of adjustment for spacing the electrodes or the pairing of the materials, the inductive and ohmic resistances in the discharge circuit, including the spark-gap, also have a certain effect. This shows the need for taking measurements of the reactions in the spark-gap in order to compare the characteristic number of impulses, or series of impulses, as to cause and effect.

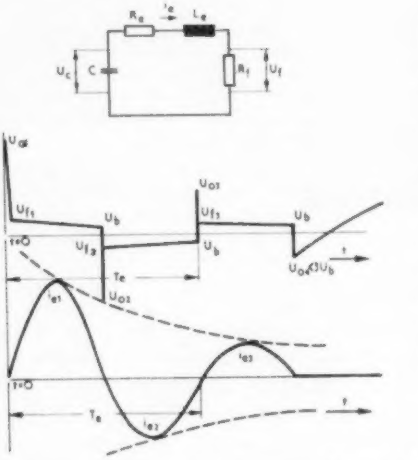
For investigating the metallurgical properties of surfaces worked by spark erosion, an attempt should therefore be made to arrange the phenomena observed in terms of the mechanism of electrical erosion in order to be able to determine the effects of changes in impulse characteristic numbers on the surfaces.

Measuring the electrical power in the discharge gap

The electrical power in the discharge gap is represented by the product of the work of the individual pulses A_f and the mean frequency of the discharge sequence f_f.

If we examine on the oscillograph current and voltage per unit time of the individual discharge, we get the sequence shown as a graph in fig. 1. At the start of the discharge the voltage u_f collapses from the value u_o to u_{f1} and then falls during the discharge to u_b. Corresponding to the oscillating character of the discharge, u_f then reverses polarity so that the second half-wave rises from u_{f_2} to u_b. The course of the current as traced beneath can be described as a damped sine wave oscillation with the momentary peak value i_e. The third value to be determined is the duration of the oscillation period T.

As the discharge gap is non-linear resistance, the work of the discharge is calculated with sufficient accuracy as the product of the mean value of the voltage and the current as well as the discharge time for a half-wave as:—



1 *Curves for current and voltage at the resistance represented by the discharge gap R_f*

$$A_{fb}=\frac{u_{fb}+u_b}{2}\cdot\frac{i_{eb}}{\pi/2}\cdot\frac{T}{2}\quad(b=1, 2, 3\ldots)$$

The entire impulse work is found from the number of half-waves to be

$$A_{fges}=\Sigma A_{fb}\ .$$

The number of discharges in unit time can be determined from an oscillogram or by the use of a suitable measuring instrument so that the power in the discharge gap can be given as

$$N_f=A_{fges}\cdot f_f$$

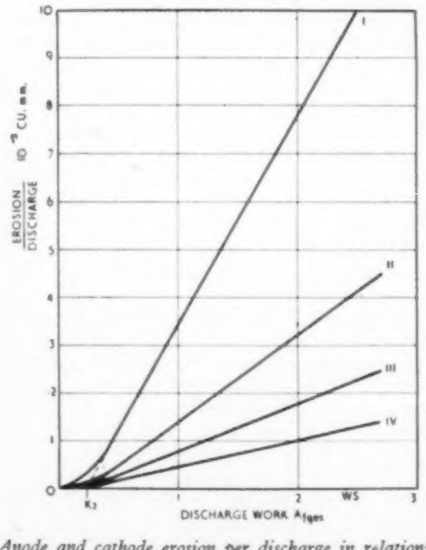
We cannot go further here into the connection between the values thus found and the components of the electrical circuits. The linear relationship between the impulse work and the material removed was capable of being confirmed during the test.

The graph in fig. 2 shows the values obtained from the test. Whereas the values found for steel as the anode material are dependent on the pretreatment, a noticeably smaller removal of metal is noted with copper. This is of special interest as regards the electrothermal signification of the erosion process—to be considered later—if the thermal conductivity of the anode material as well as the melting point is taken as a criterion. Further, a deflection of the curve to the origin of the coordinate can be seen at the abscissa K_2. Whereas above this value and consequently within the practical range of utilization of a spark-erosion machine a direct relationship between the whole of the converted energy in the spark gap and the material removed can be observed, in the lower range the form of the impulses and the distribution on the positive and negative half-waves must be taken into consideration.[1]

Theories on the mechanism of the removal of metal

Lazarenko[2] gave a first explanation of the individual impulse. According to this worker metal particles are melted by the impulse during the disruptive discharge between the electrodes and these particles, together with a part of the soft layer beneath, are flung out sideways by the dynamic force of the impulse so that a crater is formed on the surface of the metal. This interpretation has been amplified and extended by various authors. Thus S. W. Lebedew[3] attributes the heating of the material to the Joule effect during the passage of the discharge current through the metal surface.

B. N. Solotych[4] divides the erosion phenomena into two phases. In the first there is partial vaporization of the material as well as weakening of the cohesion of a certain quantity of metal in the surface of the electrode. A maximum of 25% of the material is thus removed directly through vaporization. In the second dynamic phase both the loosened and melted material is removed from the spark crater by the mechanical pressure wave during the course of melting and the vaporization of the dielectric liquid and also the electrostatic and electromagnetic forces arising from the impulse current in the spark gap cause the electrode material to be flung out.



2 *Anode and cathode erosion per discharge in relationship to the discharge work (overall view)*

E. M. Williams[5] attributes the erosion phenomena merely to the effect of electrical forces. Thus he calculates, for a discharge on to tungsten carbide with a 5,600-A. peak current a force of 102·5 kg./mm.² which acts on the underside of the loosened material particles. Our own calculations by Williams's method gave forces of the order of 10 kg./mm.² when working hot-forging steel. In both cases it appears impossible that detachment of the material can take place without previous softening of the material through the effects of temperature.

Williams's theory is supported by experiments made by E. Smith.[6]

A third among the previously mentioned basically different theories was put forward by S. L. Mandelstamm and S. M. Raiski.[7] The erosion is attributed to 'flares' observed during high voltage gas discharges. Jets of gaseous metal in the form of flares emerge from the surface of the electrodes and cause mechanical removal of material through their high speed as they reach the counter-electrode. Thus the removal of metal is not directly linked with the spark discharge but represents a secondary phenomenon.

According to our own observations, more especially of the change in the surface layer of the material worked, Lazarenko's and Solotych's theory of electrothermal erosion gives the best explanation of the phenomena. Here the question of the temperature arising and the duration of the action are of special interest. As regards the height to which the temperature rises, very different findings were made, the figure varying between 10,000 and 50,000°C. In a Russian publication by Palatnik and Ljulitschew,[8] the authors give an approximate equation based on spectrographic measurements. According to this, the temperature as a function of the loading capacity is

$$T = 7{,}200 + 450\sqrt[3]{C} \text{ (in °C.)}$$

The temperatures at the impact point of the spark discharge will be correspondingly lower.

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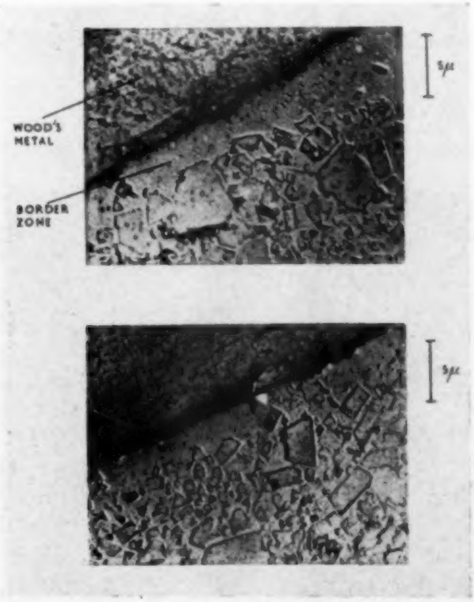
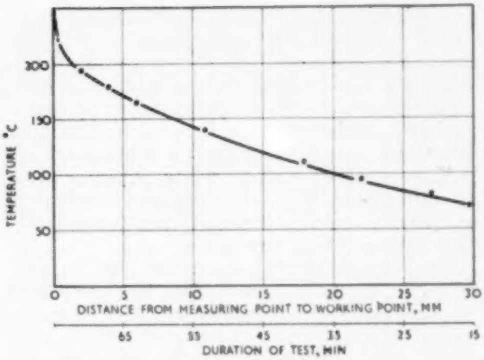


3 TOP *Electron microscope examination of the border zone on cemented carbide 62 after being worked by spark die sinking* BOTTOM *Finished work*

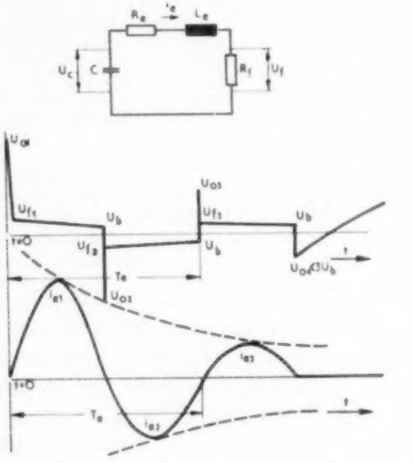


4 *Temperature curve in the tool electrode*

Fig. 4 gives a graph of the average temperatures in the work-piece during the roughing of steel. These were measured with a thermo-couple built into the work-piece. In order to prevent any effect from the coolant flow this was interrupted at the moment the temperature was taken. The curve shows that heating continuing for any noteworthy time can only occur directly under the surface, that is, the short temperature impulses are very quickly carried off via the work-piece or the dielectric.

Structure and composition of the surface layer affected

On the strength of these basic observations we will now report on the results of trials with a spark-erosion machine with a high input power, such as those mainly found in the tool-making field, that is, for turning out die blocks and cutting tools.



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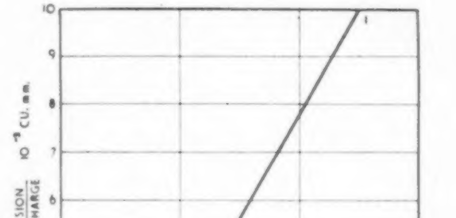

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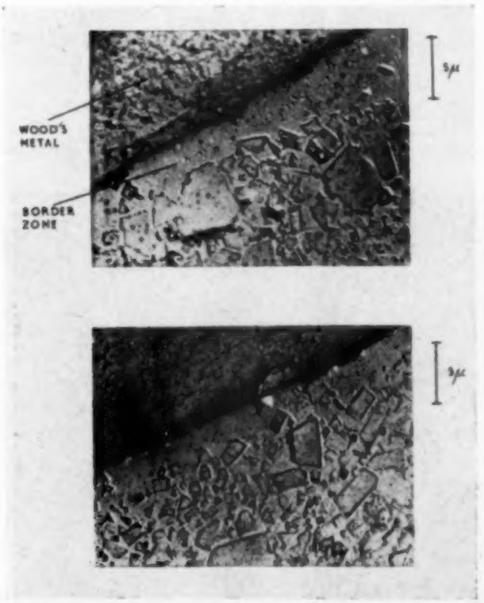

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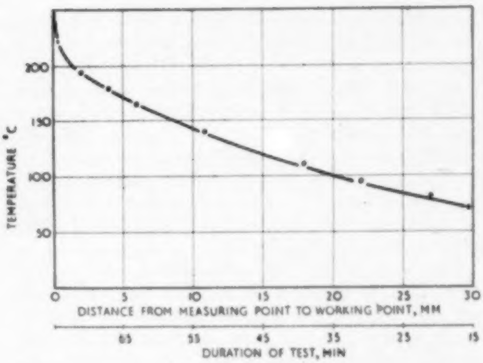

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On the strength of these basic observations we will now report on the results of trials with a spark-erosion machine with a high input power, such as those mainly found in the tool-making field, that is, for turning out die blocks and cutting tools.

Corresponding to practical requirements, test specimens of treated hot forging steel were worked with copper tool electrodes. It should only be mentioned here that by adopting special material such as, for instance, Cu-W composite materials, somewhat more satisfactory results can be obtained. However, their field of utilization is restricted for the moment to the making of fine engraving work and perforations in cemented carbide because of the high cost of the material and the limited possibility of non-cutting shaping.

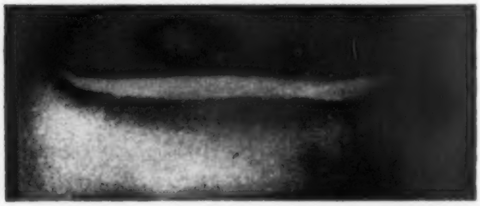
The test-pieces were distributed on a plane perpendicular to the surface of the work-piece and care was taken to see that the zones affected, as the result of the spark-erosion separation of the test-pieces, were removed before the polishing and etching carried out for metallographic purposes.

Fig. 5 is a ground cross-section through the bottom of a sunk die after roughing. Two different zones can be distinguished. The so-called 'border zone' can only be recognized in certain positions and is formed irregularly. To this is joined a conversion zone with a gradual transition into the basic grain structure.

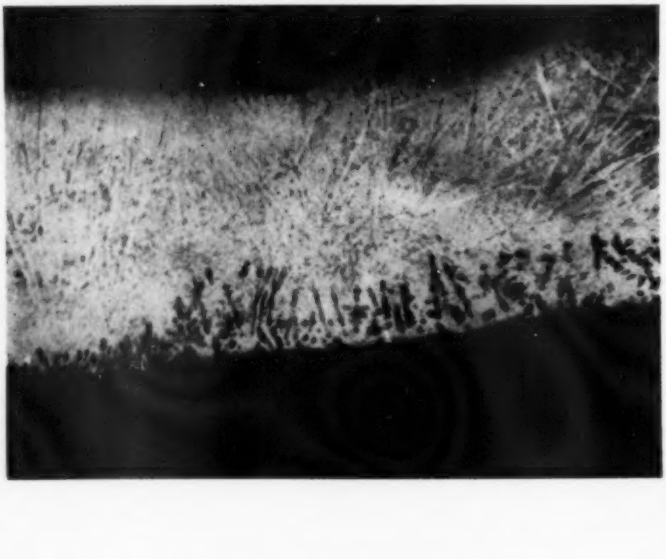
In fig. 6 the sharply delineated white border zone shows up the structure after more prolonged etching. The ledeburite structure changes from the outside inwards from a hyper to a hypoeutectic concentration. An etching on cementite confirms the assumption that it is a question here of primary cement crystals in a ledeburite matrix. The Vickers hardness of the needle-shaped primary crystals was found to be 1,000–1,100 kg./cm².

In further experiments an attempt was made to explain the formation of a ledeburite grain structure in a steel with a carbon content of 0·5–0·6%, together with slight alloy constituents of Mn, Cr, Mo, Ni and V. A half-hour's annealing treatment of the test-piece at 850–900°C. and slow cooling off in the furnace produced no grain structure change in the border zone. This phenomenon is otherwise only possible with carbon steel with a C content of more than 1·7%. After annealing for three hours at 1,145°C. in a neutral atmosphere and with slow cooling off in the furnace, there was found an intermediate stage structure with 600 kg./mm.² Vickers hardness instead of the graphite separation expected. The cause of grain structure formation of this kind must be sought in the constituents of the alloy though the 1·3 Ni content shown is too small to initiate this effect. Fig. 7 shows, in addition to the conformity of the border zone structure with the grain structure of the particles of material, that in both cases copper inclusions could be observed.

Alloying with copper from the tool-electrode is directly possible with the temperature reached. According to Houdremont,[9] the common conversions maximum for pearlite and the intermediate stages is displaced to somewhat longer durations by this addition of copper. Its appearance is also noticed in a Cu-Ni-Mo steel during lengthy cooling



5 ABOVE *Ground cross-section through sunk die after roughing*



6 RIGHT *White border zone after more prolonged etching*

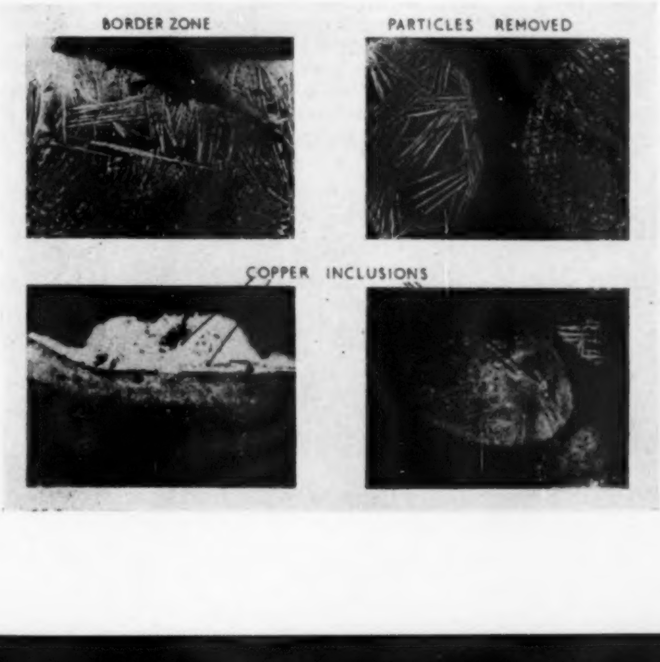
off in the furnace. Accurate statements cannot be made as to the absolute amount of the carbon content since, as a result of the presence of ledeburite constituents, the ledeburite point may be displaced to values below 4·3%. Since no further carbon carrier appears during the work, the carbon must have been taken up from the dielectric. Attention has already been drawn to the varying carbon concentration in the border zone. In the same way, ledeburite of hyper and hypoeutectic structure can be recognized in the particles of material removed shown in the ground cross-section.

A further test was made to confirm carburizing from the dielectric. The material of the workpiece was melted down with a welding torch and the falling material chilled in dielectric fluid as well as in water. The ground sections in fig. 8 show the grain structure resulting. The test-piece chilled in the dielectric shows a eutectic structure at the edge which becomes hypoeutectic towards the inside. The comparative test shows a pervading martensitic grain structure after water cooling. It should be pointed out in this connection that carburizing from the dielectric fluid is already possible from the fused mass during cooling. Attention is further drawn here to the results obtained by Hanke.[10] He found when investigating the hardening of tool-cutting edges by means of electrical discharges that there was also ledeburite in the surface if a carbon electrode was used for sparking. In this case the carbon electrode was the carbon carrier instead of the dielectric. On using a tungsten electrode on the other hand, the formation of an austenite zone and a mixture of austenite zone and a mixture of austenite and martensite could be observed.

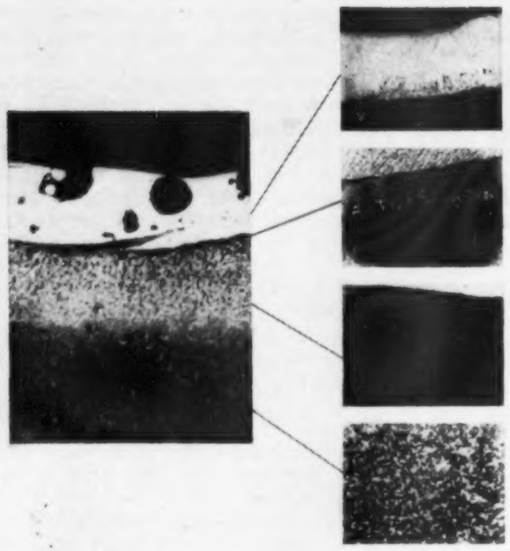
In addition to the border zone formation in the form already described, surface layers were also observed whose structure could not be made visible by etching. In this case the hardness of the border zone was in the same range as the hardness of the basic structure. Further assertions regarding the structure or the origin of this type of border zone cannot yet be made though it seems obvious presumption that the energy and the time elapsing during the impulse discharge lead to different results. From the particles removed, as shown in fig. 7, it was already possible to demonstrate the difference in the carbon concentration.

Rüdiger and Winkelmann[11] also noticed a non-etchable 'white covering layer.' The authors observed that with planed test-pieces this border zone was far harder than the basic grain structure; with increasing power used for removing the material the hardness fell to below that of the basic grain structure. In the tests with pure iron as test-piece material, carburizing of the border zone with 0·03–0·28% C were observed. Furthermore, the appearance of copper and also copper oxide was also confirmed after working with copper electrodes.

Fig. 9 once again shows the distribution between the border zone, conversion zone and basic grain structure on a basic specimen. The individual conversion stages should also be demonstrable as a result of varying hardness as well as by metallographic investigation. Fig. 10 shows the hardness curve for a test-piece with a ledeburite border zone. While the formation of the conversion zone is



7 *Grain structure in the border zone and in the metal particles removed*

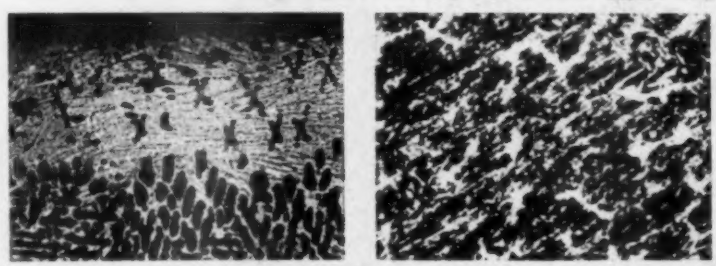


9 *Grain structure formation in the surface of steel test-piece worked by spark erosion*

generally similar, the intermediate austenite layer could only be detected in a few cases. In the same way the hardness of the border zone also varies, as previously mentioned.

According to the observations referred to, the formation of the affected zones can best be explained by an electrothermal demonstration of the process of removing the metal. The material is heated up to melting point and above at the impact point of the spark discharge. In this phase the carbon is taken up from the dielectric. The depth of the melted zone is clearly ascertainable by the boundary between the border and conversion zones. As the projecting crater rim in the example of a single discharge in fig. 11 shows, the softened material is flung outwards towards the sides. In addition to the electrostatic and electrodynamic forces there is also a particularly active mechanical pressure wave which occurs during the sudden vaporization or burning of the dielectric fluid within range of the spark flashover.

The material solidifies in the dielectric fluid into the spherical shaped particles removed from the metal as shown in the right-hand photo. A residue, however, again solidifies at the bottom of the crater or condenses on another part of the surface and thus forms the border zone as will later be observed. This hypothesis is, in addition to the carburizing of the border layer, also illustrated by the pore-containing and non-uniform nature of the



8 *Grain structure formation of hot forging steel when solidified after melting*

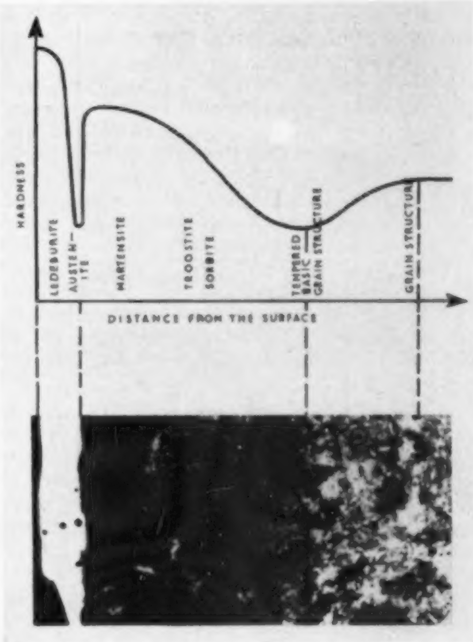
surface. In these pores, which could also be observed in the particles removed from the metal, many oxide inclusions could be detected.

If it is furthermore presumed that the point of the spark flashover constantly moves forward to a position where the space between the electrodes is least, in the same way the dielectric fluid flows after it with every flashover and suddenly cools this position off. At the same time there follows cooling from the thermal conductivity of the test-piece. This cooling effect prevents the separation of carbon in the form of graphite and results in the metastable phase of the iron-carbon-eutectic, the ledeburite, after the primary separation of primary Fe_3C crystals.

The further modifications in the conversion zone the changing temperatures and cooling speeds occurring through thermal conductivity in the test-piece.

Factors causing the formation of the surface layer

According to the results so far discussed, the type of change in the grain structure occurring in the surface of the test-piece is dependent on the temperature and its duration in the working gap. As measurable quantities, however, the only ones that can be arrived at are the impulse work and impulse sequence or the power involved in removing material. Fig. 12 is a graph showing the connection between the power used for removing the material and the width of the zone. The reference measurement selected was the capacity of the discharge circuit which is at the same time a measurement of the work of the individual impulses. It is a fact of importance that decreasing the power involved in removing metal by reducing the sparking frequency by higher capacity is reflected in the width of the border and conversion zones. This indicates that it is not the energy of the individual impulses but the converted power in the working

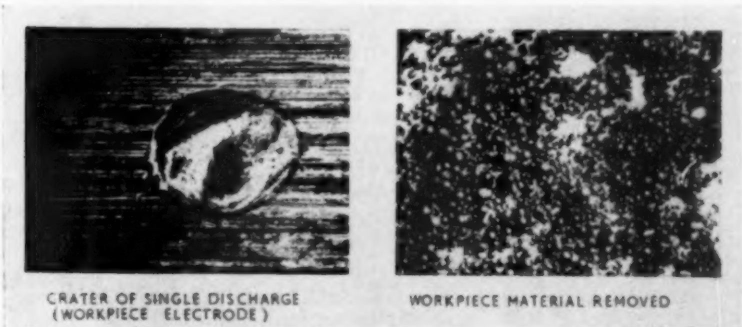


10 *Hardness curve in the surface of a spark-eroded steel test-piece*

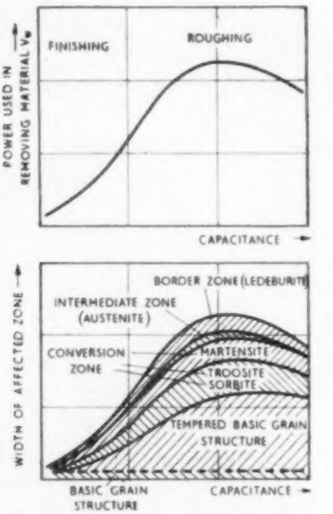
gap that determines the depth of the surface changes.

The diagram purposely only gives the course of events reduced to a norm since absolute values are largely dependent on the machine. In addition, the width of the zone is changed by the layout of the ' boring ' arrangement as well as by any flushing that may be used.

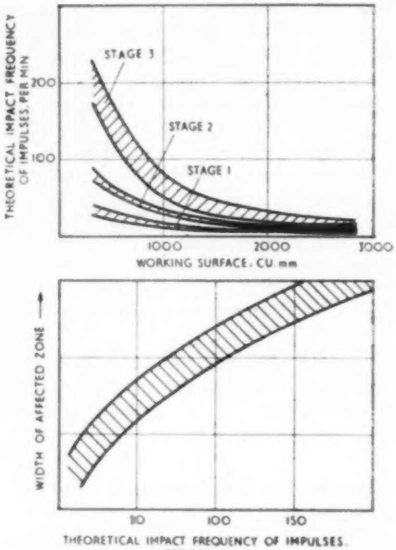
The effect of the ' boring ' layout is brought out more clearly in cases of deep engraving of compli-



11 *Electrothermal demonstration of the process of metal removal*



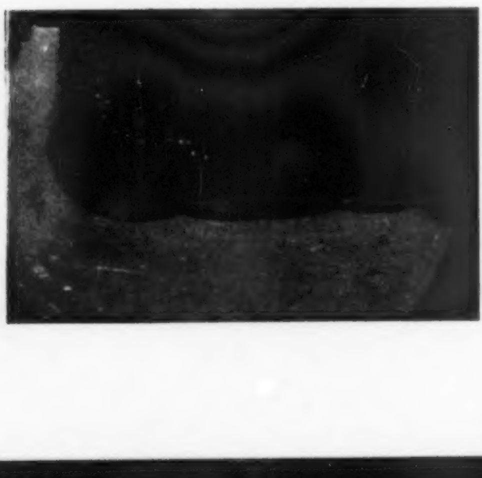
12 *Connection between power used in removing material and effect on surface for spark-eroded steel*



14 *Connection between the working surface and effect on the border zone. Tool electrode, copper* 20, 40, 60 *mm. dia. Work-piece, hardened steel* 20, 40, 60 *mm. dia. Voltage, stage* $I+3$. *Capacity, stage* $II+IV$. *Duration of test,* $T=20$ *min.*

cated shape or when the depth of working is considerable in relation to working surface. Fig. 13 gives an example of a partial section made by boring vertically. The largest zone width is seen at the edge of the lower surface, while on the upper part of the shell surface, on the other hand, practically no conversion zone has resulted. This phenomenon can be explained where there is blind-hole ' boring ' and is due to the greater difficulty of evacuating the products of erosion. The pressure produced during the discharge is no longer sufficient to eject completely the particles of material removed as well as the carbon from the working area; guiding bridges are formed which may lead to arc ignition.

13 *Partial section made by vertical boring*



As a further effect of the ' boring ' layout it was noticed that the width of the zone, under the same operating conditions, is dependent on the size of the surface. If mean values for the diameter of individual craters and the average frequency of the discharge sequence are taken as a basis, we get the position shown in fig. 14. With a constant impulse sequence, the impact density φ at a given point on the working surface decreases as the area becomes greater. We thus get the equation:

$$\varphi = \frac{f_f \times F_K}{F_A}$$

where

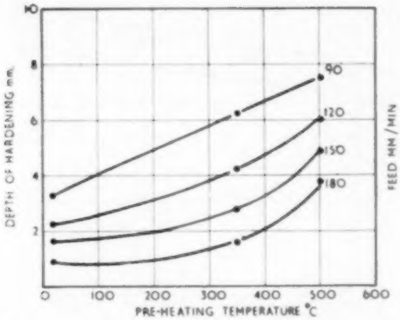
f_f = average frequency of the discharge sequence

F_K = area of the crater

F_A = working surface

However, the average heating of the surface of the test-piece and, with it, the width of the conversion zone, will also change with the impact frequency. If these are plotted over the theoretical impact frequency, the resultant measurement gives the curve shown in the lower part of fig. 14.

Similar conditions can be observed with oxy-acetylene surface hardening.



15 *Effect of pre-heating temperature on the depth of hardening with oxy-acetylene surface hardening* (*Bühler*)

The graph in fig. 15 (according to data by Bühler[12]) shows an increase in the depth of hardening with rising pre-heating temperatures as well as a reduced feed rate during heating up. It is thus possible to notice a similarity between the pre-heating temperature and the average heating up as well as between the feed rate or duration of the effect and the spark power.

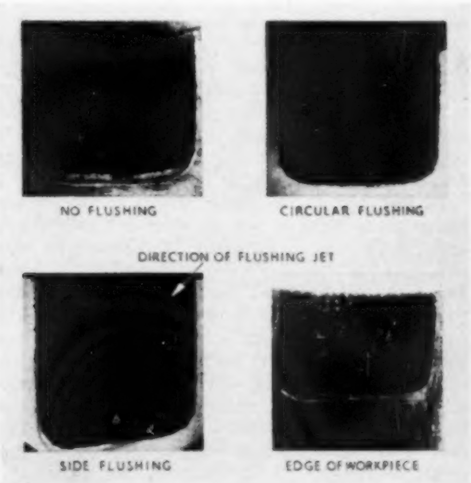
The role of the dielectric fluid consists, in addition to the continual de-ionizing of the spark gap, of carrying off from the working point the material removed as well as part of the heat caused by the spark flashovers. With deep engraving or complicated shapes a fresh supply of the working medium is often necessary.

According to the findings so far, the average heating up and with it the width of the zone must change with flushing of this kind. In fig. 16 (top) two longitudinal sections through a vertical round hole are shown side by side. The left-hand hole was made without flushing, while in the right-hand one the whole working surface was uniformly flushed. The affected zone, which is plainly evident, especially at the bottom of the hole, has become very narrow when flushing is used. The actual border zone can be recognized in both cases; the flushing has mainly affected the width of the conversion zone. The continual supply of fresh working medium thus reduces the average heating up, while the formation of arcs is eliminated by the carrying off of the products of erosion and the more rapid de-ionizing in the spark gap.

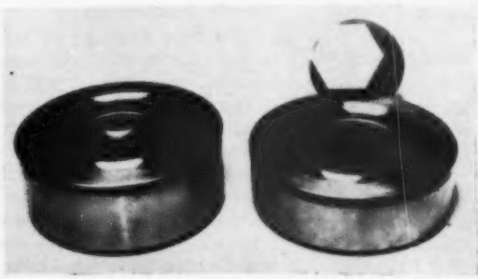
Before making use of flushing, however, another phenomenon must be taken into consideration. Fig. 16 also shows the longitudinal section through a hole which was flushed during the work by a jet of fluid directed on one side of it. The original shape is so distorted that a shallower depth was reached on the side on which the jet of liquid entered as a result of less power being available to remove metal and because of increased wear on the tool. At the same time, no transition zone can be recognized on this side. On the less heavily flushed side of the bottom of the hole a wide transition zone has, on the contrary, been formed. There is an obvious presumption that a portion of the erosion particles carried off by the flushing jet has choked up and has contributed to the formation of an affected layer through arc ignition. In other tests, too, the flushing could be seen as the origin of the reduced power for removing metal with increased wear. It follows from this that flushing certainly operates favourably as regards reducing the effect on the surface, but can lead to distortion of shapes in connection with the direction of the jet flow.

In conclusion, we would draw attention to the question of the adjustment of the spacing between

16 *Effect of flushing with the dielectric fluid*



17 *Test dies used in wear-resistance tests*



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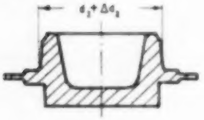
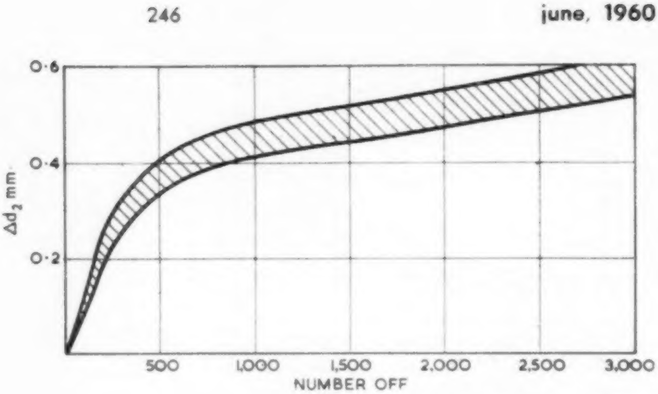
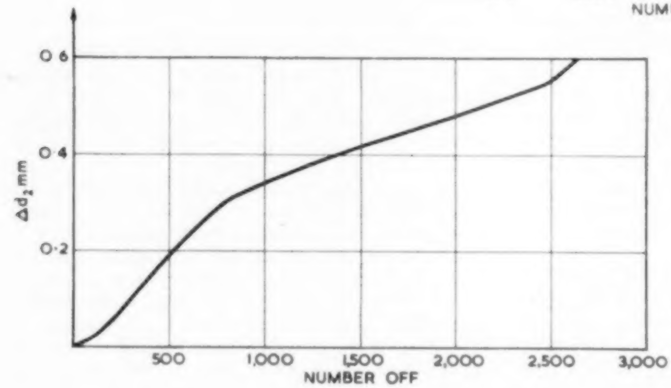




19 ABOVE *Dies PB 73 and PB 74. Material 2713. Turned and emery polished. Depth of roughness $< 5\mu$.*



20 LEFT *Die PB 82 Spark eroded (die not turned). Depth of roughness 20-40μ.*

the tool and the test-piece. There must be accurate response in reaction to slight variations in adjustment with adequate speed. Only in these circumstances can the conditions at the spark gap be held constant and the arc ignition due to contamination or bridge formation prevented or quickly interrupted. In some cases there is additional provision, through suitable switching arrangements, for interrupting the current in case of short-circuit to prevent deep burning through arcing. It might just be suggested here again that adequate cleaning of the working medium is a prerequisite.

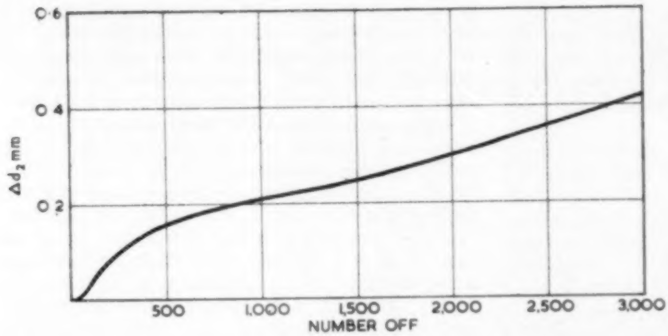
Wear tests on die engravings made by spark erosion

The results so far considered have shown that changes take place in the composition and grain structure of the surface of tool steel worked by spark erosion. Practical experiments should show in what direction these affect the resistance to wear and thus the number of stampings off the dies.

The accuracy of reproduction required as well as the quality of the surface make it essential that an engraving shall be produced in several operations and with two to four working electrodes used one after the other. It will be seen from fig. 12 that as the power used in removing material falls and consequently the roughness values, the depth of the effect on the surface becomes less. It is thus possible, by correctly choosing the course of operations, to obtain only a very narrow border and conversion zone after the final finishing.

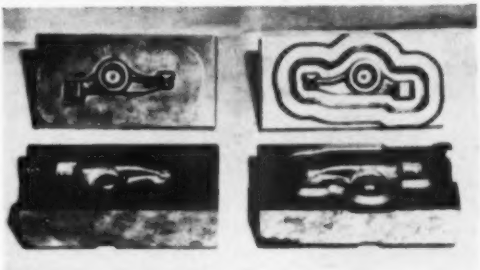
The variation in the results obtained as a result of a number of influences when forging dies gives only a generally valid picture of a large number of experiments. The values obtained from three die-sinking experiments made in collaboration with the research section of the Hanover Technical College do, however, show specific features.

In test dies of the shape shown in fig. 17 the resistance to wear of two spark-eroded dies, PB 82 and PB 83, was investigated by comparison with two dies PB 73 and PB 74 produced in the usual way by turning and polishing with emery. Of the spark-eroded dies, PB 82 was produced from the solid by means of four working electrodes using roughing, pre-finishing and final finishing operations. The second die was pre-turned mechanically to within 1 mm. and was only worked under finishing conditions with two tool electrodes. The dies were put into use without any subsequent finish grinding.



21 LEFT *Die PB 83. Spark eroded (die turned to 1 mm. normal to hollow-shape surface). Depth of roughness 20-40μ*

22 BELOW *Tool electrodes and die inserts for rocker arm*



When forging, care was taken to see that all the conditions such as material, temperature, lubrication, etc., were kept the same.

The course of the wear was noted by means of lead impressions which were taken after every 250 stampings.

The alteration in the diameter Δd_2 (fig. 18) was taken as the measurement indicating wear and this is plotted over the number of parts turned out in figs. 19 to 21.

In both the spark-eroded dies wear began later. In spite of the flatter initial part of the curve, this curve attained the wear-curves of the comparative dies with their steeper start and subsequent flatter contour.

The best results were with die PB 83 that was first produced mechanically and then finished by spark erosion. It is only possible to presume that in this case the reduced thermal stresses during the machining led to this result. A general assessment is not yet possible from these tests.

Provisional assessment

However, the stability of the surface design of the die sinking was generally better and the appearance of cracks could be noticed. A qualitative analysis of these results on the basis of the lead impressions shows scarcely any appreciable difference as against forged dies. The number of stampings was of the same order for all the dies observed.

Metallographic investigation of dies PB 82 and PB 83 showed no vestiges of the border zones that had appeared during the working. Only at one point could a more deeply burnt-in spot (obviously due to arc ignition) be recognized. Comparison of the state of hardness in the surface of the eroded and comparative dies after forging showed no recognizable difference.

Further tests will bring to light what effect different stages of pre-working have on the number of stampings from the dies. It is of interest that the relatively rough surface of the eroded dies (with a roughness depth of 20–40μ maximum), merely had to be lubricated somewhat more during the first ten stampings than the emery-treated dies. The complete number of sticking stampings showed no difference when compared.

In conclusion, we would mention a working comparison made between two hot-forged and spark-eroded finished die inserts. The dies shown in fig. 22 with the tool electrodes used for making them gave the same number of stampings. These results have been confirmed through reports on work in practice.

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AUTHOR'S SYNOPSIS

Professor Dr.-Ing. H. Opitz, delivering the synopsis of his paper, first thanked the National Association of Drop Forgers and Stampers for its kind invitation to him to present his paper and take part in the discussion.

The Professor then emphasized that, besides the investigations regarding operation instructions for the practical application of spark machining, die sinking and tool making, it was of great importance to study the influence of this machining method upon the wear and output of such machined blanking or forging dies.

As a basis of a reference system, which gave a connection between the results of machining a work-piece and the adjustment values, some characteristics of discharge circuits were discussed at first.

The electrical power consumed in the spark gap was represented by the product of the work of an individual discharge and the mean frequency of the discharge sequence. Fig. 1 showed the schematic curves for current and voltage of such an individual discharge as received by oscillograph. From the oscillogram the amount of work of the individual half-waves was gained by multiplication of the mean value of the voltage and the current according to the equation given in the text. The work-rate of all the half-waves of an individual discharge summed, multiplied with the mean frequency of the discharge sequence, then represented the above-mentioned electrical power consumed in the spark gap.

As a reference value in diagrams it was useful to plot the work of the individual discharge as in fig. 2, which showed the relationship between the electrical work and the stock removal of the individual spark. Within the range of most practical application the curves were geometrical ones. The gradient depended upon the polarity and the combination of work-piece and tool-electrodes material. Only the lower left-hand portion of the curve beneath 0·4 watt-seconds differed from the main part of it, on account of there being a measurable influence of the waveform and the correlation between the positive and negative half-waves. It went without saying that those experiments were not made by single discharges, because that method would reveal many mistakes. They were rather made under practical conditions and only reduced to the individual discharge by calculating.

In the following section some theories regarding the mechanism of the removal of metal were discussed. It became clear that the later described phenomena were quite well interpreted by the Lazarenko and Solotych theory, which referred to the electrothermic theory of the removal of metal. According to that explanation of the mechanism, the temperature existing in the spark gap was an outstanding feature. The melted zone discovered in the surface layer of cemented carbide metal led to the conclusion that there were temperatures of 3,000°C. and over. Measurements by thermo-electric couple pointed out that those high temperatures took place in the outer surface layer only.

Further research was done on metallographic analysis of the surface layer influenced by the temperature shocks causing a change in structure and composition.

Fig. 9 showed the cross-section etching of the surface layer of spark-eroded steel. There were three zones to be distinguished by microscopical view—the border zone, sometimes an intermediate zone, and the conversion zone. The border zone was characterized by the change of composition of the original work-piece material. Analogic experiments confirmed that the high temperatures caused a diffusion of carbon from the cracked dielectric fluid into the border zone, leading to the formation of a ledeburite grain structure.

In other cases, preferably at lower electrical power inputs, a non-etchable white covering layer was observed, the analysis of which was not yet known. The intermediate zone, appearing only after rough machining operation, was only a few microns wide and had an austenitic grain structure.

The following conversion zone was characterized by a change of structure of the basic grain. In accordance with the decrease of temperatures and quenching velocities by increasing distance from the surface, the material was hardened, tempered and annealed as far as the structure passed into the basic material. This classification and explanation was testified by the result of a hardness test noted in fig. 10.

The next section described some factors causing the formation of the surface layer. The rate of stock removal was mentioned as the main influence. The graph in fig. 12 showed the correlation between the power used for removing the material and the width of the influenced zone. Thus, in order to attain a small influenced zone it was necessary to finish the shape at a rate which guaranteed the zone, built up in the cycle before, being removed.

The surface layer width was doubly influenced by the shape of die or hole. In deep holes of small cross-section or with sharp angles, swarf removal was rendered so difficult that arcs took place, which caused a wider modified zone than results from the normal spark-cutting process.

The cross-section of work area was found to be another effect on surface layer width. With larger work areas cross-section, the average heating and with this the depth of influenced zone of the machined surface area decreased, constant operation conditions provided.

Fig. 16, finally, showed some effects resulting

from flushing test holes by dielectric fluid during the machining process. The affected zone had become very narrow, but it must be observed that the original shape was distorted in comparison with the hole that was not flushed. Therefore, the flush must be carefully arranged if an exact shape was to be obtained.

The last section discussed some first results of forging tests with dies machined under definite conditions. The forging work in this research was carried out under Professor Kienzle at the Technische Hochschule at Hanover. Comparing the output of dies produced in the usual way with those produced by spark erosion, there was no difference evident. The curve of wear rate increase showed that the beginning of wear was later with spark-eroded dies, and that with the mechanical pre-machined die the gradient of wear increase was less steep than with the others.

In conclusion, Prof. Opitz emphasized that reliable results could be gained only by many tests exploring the various influences on die life of the spark-machining process.

DISCUSSION

Mr. D. Payne (Deritend Drop Forgings Ltd.) said that it was quite apparent from Prof. Opitz's paper and synopsis that industry had entered into a completely new metallurgical field. Transformations were being dealt with at temperatures hitherto almost practically unheard of, with extraordinary accompanying changes. The changing composition of a steel from a normal die steel content of medium carbon to one to produce a ledeburitic structure was an incredible process. The significance of that change of structure was important.

The change in structure at and adjacent to the surface of the spark-eroded impression was dependent on the precise eroding conditions—rate of metal removal, degree of flushing, the geometry of the cavity, etc. The impression face might ultimately vary in hardness from something similar to the unaffected zone, that is, the original die steel zone, to about 1,000 or more Vickers hardness numerals. Mr. Payne asked for Prof. Opitz's opinion of the optimum condition at the surface from the point of view of die life, considering wear resistance and the possibility of thermal cracking in service. Would it be necessary to sacrifice advantages which could be gained by the production of this ideal surface layer due to limitations which it would economically impose on the mechanism of sinking the impression? Would industry be faced with the prospect of having to abandon an ideal structure which could be achieved, because economically it would not be in keeping with die-sinking practice?

Prof. Opitz, replying, said that the disturbed zone must be kept very narrow. It was not possible to begin spark machining with a very great amount of material removal, otherwise the depth of distortion would be very high and the final operation would not clear the whole die. The disturbed zone must be brought out, otherwise there would be scraps and splittings of the hardened zone. Some experience was necessary to make the best arrangement of the pre-machining and the final process in the sparking.

Mr. R. W. Shapton (Rotax Ltd.) commented that spark machning had been used for aircraft components in various materials. Metallographic examination had revealed alterations in the surface structures indicating, as Prof. Opitz had said, that very high temperatures had been attained during spark machining. The effect of such heating was to produce a hard layer on the surface and in some cases cracking. As this appeared to be a normal effect of spark machining, what was the effect on fatigue properties?

Prof. Opitz said that for parts which had to have a great fatigue characteristic the process must be very carefully carried out. With a very small amount of material removal, a very good surface finish might be achieved. Regulation of the speed of the electrode also gave a good surface. He did not believe that for very heavy parts it was good to make sparking a normal machining method.

Mr. B. Kennedy (Firth-Derihon Stampings Ltd.) asked whether the depth and hardness of the resulting surface were affected by the material used in the electrode. If so, how could this be controlled?

Prof. Opitz replied that so far they had not found that different materials for the electrode made any difference. Care must be exercised, because the sparking method was very new and much research remained to be done. Fifty years' research work had been carried out on normal machining, and still many things were not known. Much less was known about the new method of sparking.

Mr. R. A. Riley (Alfred Herbert Ltd.) said that it had been claimed that tools ground by spark machining outlasted conventional finishing. Had Prof. Opitz any experience of this, and could he compare it with ground finishes or lapped finishes?

Prof. Opitz said that they had heard stories about increasing tool life by using the sparking method to clear the surface, but they had carried out much research work and had not found a clear preference for the sparking method. Normally, tool life was not much longer than with normal grinding by a grinding wheel. However, there were great differences from grinding a tool with a wheel; very good surfaces or very bad surfaces might be obtained. It was governed by the method

of grinding. They had not found that a better tool life resulted from sparking.

Mr. B. Robinson (Clydesdale Stamping Co. Ltd.) said that he had not found in the paper any mention of temperature of the spark gap. At any particular instant would there be sufficient heat generated at the spark gap to cause oxidation of the grain boundaries?

Dr. H. Obrig (Aachen Technical College), answering for Prof. Opitz, explained that oxidation would not be possible there, because the process took place in the dielectric fluid. They had not found any traces of oxidation in the surface layer zone.

Mr. F. C. Bird (Walter Somers Ltd.) asked about the rate of metal removal as conditioned by the nature of the metal being dealt with. Was there any evidence that the rate of metal removal was governed by the alloy content of the material? Was there any preference for nickel, chromium or molybdenum which would govern the economics of the process?

Prof. Opitz regretted that he was unable to answer this question. Up to the present they had dealt only with the normal materials for dies. They had had no experience with alloy materials.

Mr. K. Appelbee (Metropolitan Vickers Electrical Co.) asked whether in the examination of surfaces of spark-machined materials, Prof. Opitz had done any work on the phenomena known as spark hardening. A number of firms in the U.K. which had been involved with spark machining had marketed equipment for spark hardening. Was there any possibility of inducing a material transfer, for instance, after a normal spark-machining operation, to deposit possibly a hardened layer on the die to give some advantages in the wear of the die?

Dr. Obrig replied that no investigations on this point had been carried out in their laboratory. He had read a paper from Eastern Germany in which it had been stated that the effect of higher tool life by sparking tools was not the diffusion of material, but more the hardening by the high temperatures in the surface layer of the so machined tool.

Fatigue fracture

IN GENERAL, the fatigue fracture of metals is smooth in appearance with either a white or black colour. Although a very large number of investigations on fatigue strength and the mechanism of fatigue have been reported, there does not appear to have been any metallographic study of fatigue fracture. A recent note on some Japanese work[1] on microstructural observations of fatigue failures is therefore of interest, and a short summary is given below. The work deals with both mild and hard steels, with particular reference to locomotive tyres and rails, but it is possible that the conclusions reached may be of more general application.

Specimens of 0·2% carbon mild steel were tested in a Wöhler type fatigue testing machine, and the area of the material in the immediate vicinity of the crack examined with the aid of a high-power microscope. The examination shows that the fibrous structure of the material loses its directivity and that the grain size is reduced. Hardness measurements show an increase in hardness of some 25% over that of the unaffected metal and, although this hardness may be affected by internal stresses, there is obviously a structural disturbance.

For the hard steel, specimens taken from locomotive tyres with fatigue failures show similar structural changes and the examination of microphotographs obtained under high magnification again shows an abnormal structure within the crack region. It is extremely hard, with a hardness value comparable with heat-treated carbon steels, and cannot, therefore, be explained on a simple cold-working basis.

It is concluded from these tests that along the fatigue crack isolated abnormalities develop, containing a martensite structure. These are presumed to originate from an initial crack which develops internally, but under heavy pressure on the tyre the resulting friction causes the rough surface of the crack to turn smooth. The metal dust produced by the wear is sintered by the friction heat and then quenched and hardened in the mass of the tyre. The abnormalities are assumed to grow out of the repetition of this process. This would explain the martensitic structure in the vicinity of the crack, and it should be noted that martensitic change of structure causes volume increases and embrittlement, which are considered to promote fatigue cracking.

It is suggested that, due to the large rise of temperature due to frictional heat, the cracks which form in the presence of oxygen present a black smooth fracture region, while those formed without

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oxygen have a white smooth fracture when viewed under the microscope. The above conclusions are based on tests of locomotive tyres and rails which have the characteristic of a large mass under very high external forces, which may contain internal fatigue cracks with no means of escape for the worn metal dust, but they may also be applicable to other similar stress conditions.

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Automatic copper rod rolling

During the post-war years, British Insulated Callender's Cables Ltd. has spent large sums on research and on the introduction of the most modern and efficient plant. Last month a new fully-automatic copper rod rolling mill was officially inaugurated by the Rt. Hon. Reginald Maudling, M.P., President of the Board of Trade. The new mill, entirely British designed and built at a cost of approximately £1,500,000, is the largest and most advanced in the world. It will process large quantities of copper from the Commonwealth—and from Northern Rhodesia in particular—into high-quality rod for home use and export. Seen above, the President is starting the new mill, Mr. W. H. McFadzean, chairman and managing director, B.I.C.C., at his side

MANY MODERN FEATURES incorporated in the new B.I.C.C. copper rod rolling mill at their Prescot works make it unique in the world. As a unit it is a significant technical advance: it handles nearly a quarter of world copper rod production.

Copper rod, and wire made from it, are examples of vital links in the chain of our life which are taken for granted by most people. None the less, we all use vast quantities of copper wire and the demand is steadily increasing all over the world. British Insulated Callender's Cables Ltd. are the world's largest cable making organization and they export some 50% of their copper output. The main markets are the Commonwealth, particularly New Zealand, Pakistan, Venezuela, and even China, to name a few of 130 countries.

The achievement which this new mill represents can be best expressed by its capacity. Apart from push-button control at the first stage, where the hot bar enters the mill, operations are fully automatic. That in itself is a remarkable combined effort between Brightside Foundry & Engineering Co. Ltd. and B.I.C.C. engineers. The mill can convert 400 tons of copper bar into rod from $\frac{1}{4}$ to $\frac{9}{16}$ in. diameter in $\frac{1}{16}$-in. steps per day. A single bar about $4\frac{1}{2}$ in. square and 4 ft. 6 in. long, weighing between 255 and 275 lb., is reduced to 1,300 ft. of $\frac{1}{4}$-in. rod in 82 sec. This is equal to some 23–30 long tons per hour or 2,000 tons per week on two daily $8\frac{1}{2}$-h. shifts.

To meet this enormous consumption a special stockyard adjacent to the mill has capacity for 10,000 tons of copper bars. The bars are handled by two 6-ton cranes in the yard and loaded in 43-ton lots on to special cars hauled by a Ruston diesel locomotive to the mill charging area. There are

two rail tracks in the charging area, one adjacent to a shallow pit and one adjacent to four furnace charging conveyors. Every day the pit is filled with bars for night shift use, avoiding night work in the yard. At the same time the conveyors are kept loaded. Here handling is by two Herbert Morris telpher transporters which have been modified and fitted with special grabs to pick up seven bars at a time.

Walking-beam furnaces

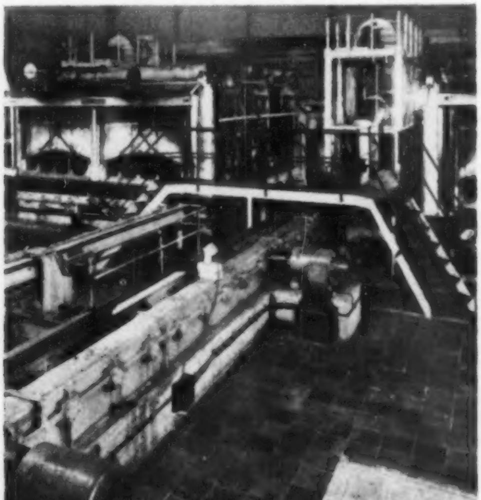
Two oil-fired furnaces by Wellman Smith Owen Engineering Corporation Ltd. each have a pair of walking-beam conveyors which are charged with bars from the outer conveyor at 3½-in. spacing by electric limit switch operation; the advance stroke is 7½ in. The heating period is about 1 h., during which time the bar is brought up to 810–830°C. To maintain this rate of operation using 12 Schieldrop self-proportioning burners in each furnace six to eight loads of heavy fuel oil are required daily.

The furnaces are situated in parallel pairs 30 ft. apart. Discharge of the hot bars is by roller conveyors, at right angles to the walking beams, leading to a cruciform turntable placed between the furnaces. The discharge and operating cycles of the four furnace conveyors are interlocked so that an alternating discharge takes place at 13-sec. intervals. The walking beam drops a bar on the rollers at the end of each advance stroke. The bar is carried into the cruciform table and turned 90° before being pushed by an electro-pneumatic ram into a roller-feed channel leading to the roughing mill. The electro-pneumatic rams are provided with air at 80 lb./sq. in. from a ring main. Two compressors and one standby unit are used, each capable of giving 300 cu. ft./min. free air and a 200 cu. ft. receiver is situated in the line. This part of the operation is under direct control from the first and main control pulpit placed high up above the mill floor. Entry to the first stand is controlled by photo-electric observation of the conveyor, triggered by the presence or absence of a hot bar.

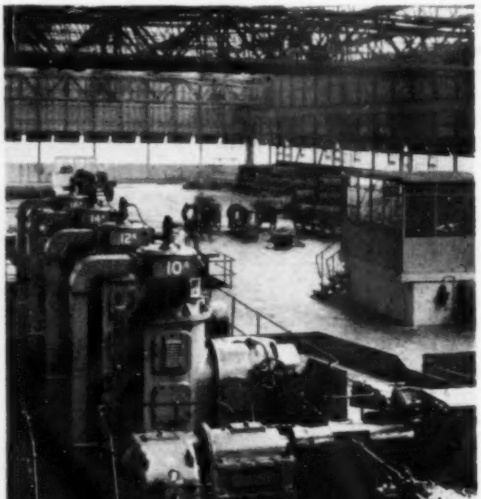
Mill operation

The first stand is a three-high-five pass-roughing mill fed by other electro-pneumatic pushers; automatic raising and side movements are used and in the five passes the bar is reduced from over 16 sq. in. cross-section to 12·427, 8·90, 5·63, 3·945 and finally 2·50 sq. in. section by 30 ft. long in 30·45 sec. The bars are transferred sideways on a transfer table and placed in an intermediate roughing train. Their advance is controlled by an automatic switching device which directs them into one of two trains alternately. It is at this switch that the mill divides into two separate sections so that two different sizes of rod may be rolled at the same time fed by one roughing mill. From the transfer table the bar travels in reverse direction controlled by pinch-rolls with photo-electric supervision to one of two 15-in. two-high intermediate roughing mills. Leaving the rolls, the bar is looped 180° on a semi-circular

Twin re-heating furnaces and main approach conveyor



One of the two continuous-finishing mills



tray and emerges 64·7 ft. long. The total time so far from the turntable is 44·65 sec.

The remainder of the mill is duplicated and provides another feature peculiar to this plant. The rod now passes directly to one of the sets of 11-in. cross-country intermediate finishing mills arranged in zig-zag formation with six looping stands each. This feature is unique in British manufacturers' rolling mills and gives a clean compact arrangement.

In the intermediate finishing stands the rod, now assuming an oval cross-section, is increased in length to 429 ft. in 8·20 sec.; the total time is 67·45 sec.

By this time, when it enters the finishing mill, a 9-in. seven-stand continuous unit, the rod is travelling at about 30 ft./sec. It takes 2 sec. to pass through the seven stands and in that time its speed is nearly doubled. To obtain various sizes of rod it is possible to bypass the last stages of the finishing mill as required to give six rod sizes with the minimum of roll changing.

The rolls of the finishing mill are 9 in. and are cantilever suspended, alternating horizontal and vertical to avoid twisting at high speed and the use of twist guides. The arrangement of cantilever suspension is unique in any type of mill in this country. The rolls are forged nickel-chrome-molybdenum steel rings.

From the finishing rolls the rod is passed via a selector switch to one of a pair of pouring-type coilers situated one at each side of a quench tank. The coil is pushed from the coiler to a lift platform, lowered into the tank and raised again to bench level. It is then taken over by a dog-chain conveyor. At the end of the conveyor a mechanical fork transfers each coil to a four-boom capstan, each boom holding nine coils. When a boom is fully loaded the capstan is rotated so that each set of nine coils may be removed with a stacker truck. The truck is a Yale K51 modified to have a single boom in place of the usual forks.

Inspection

The rod is under constant quality control which uses three main tests. First, the temperature of the wire bars is recorded at the cruciform turntable. Secondly, a micrometer check on coils leaving the conveyor is carried out every 5 min. to prove cross-sectional area. The third check is applied to test bars cut from the coils and comprises a reverse-torsion test by electrical machine. Ten turns are made in the sample to determine the degree of oxide scale present. By taking the turns off again rolling defects are detected.

Lubrication and cooling

All the roll grooves, roller guides, stripper gear and channels are provided with a flood lubrication by a $3\frac{1}{2}$% solution of Shell M.3 soluble rolling oil in water. The system comprises two settling tanks and a sump with a total capacity of 60,000 gal. There are 55,000 gal. of solution in the system at one time in continual circulation. Four pumps and one standby unit are used, each capable of delivering 600 gal./min. To maintain the supply a mixing tank of 1,000-gal. capacity is provided.

The mill stands, except for the finishing mills, are of unusual design in that they are pre-stressed. The housing closes on the rolls, which are carried on S.K.F. spherical-seating roller bearings lubri-

Loading wire bars into the twin reheating furnace

cated with Shell Alvania E.P.2 grease. When assembling the roll stand the securing nuts are tightened down and then the draw-bolt stretched about 0·015 in. and the nuts re-tightened so that the assembly is pre-loaded. Stretching is done with a simple hydraulic cylinder at the head of each draw-bolt. Pressure is applied by a small hand pump, a small quantity of Shell Tellus 33 hydraulic oil being used. An hydraulic ram jig is used for stripping and assembling the roll bearings when changing them. The roll bearings are protected from contamination by water or scale by grease-filled labyrinth seals. The seal duty is very arduous and they are re-greased after 8–9 h. running; that is, at least once per shift. There are 3,000 grease and oil nipples in the plant also requiring constant planned attention. All small motors have bearings packed with Shell Alvania Grease 3. This is a special grease developed for use in rolling bearings and gives exceptionally long service life for the bearing and grease charge.

The main pinions and gears through which power is transmitted to drive the mill are all lubricated by Shell Macoma oils. They are heavy-duty gear oils containing a special load-carrying additive which protects the gears from the high shock loads experienced in plant of this sort. Special open gear compounds from the Shell Cardium range are also in use.

By far the largest lubrication system, apart from the soluble oil, is the main pinion and gear system. This comprises 3,000 gal. of Shell Macoma Oil 68. The whole lubrication system, divided into a number of key sections, is under interlocked electrical control. The arrangement is such that, from a control panel outside the main mill building in the electrical section, the whole system can be continuously checked by tell-tale lights on a diagram panel and recorders. Standby pumps are automatically switched into circuit if required and not only flow, but pressure checks are applied to the whole circuit. In the mill itself a pair of large green lights is mounted on the wall opposite the main control pulpit. In the event of any failure in lubrication a second pair, red, replace the green lights and a Klaxon warning is sounded. The starting of the main motors is under the control of the electrical section and not the pulpits, where speed control and stopping are the only motor controls the operators have. The operation of starting the mill is interlocked with the lubrication system.

To ease fault finding the main lubrication control panel has a set of minor panels or windows—over 36 of them—about 2½ by 1½ in., each with the name of a particular section on it. Failure in any part of the mill causes the appropriate window to be illuminated.

There are two main cooling problems. First, the quench water, which is in a closed-circuit system with four pumps, two working and two standby. The water circulates at 15,400 gal. h. and is cooled from 146–96°F. by a forced-draught cooler in the circuit. The copper rod drops about 230°C. in the 82 sec. during which, to produce ¼-in. diameter, it has 20 passes through the mill rolls.

The second problem is forced-air cooling for the electrical department and the main motors. The electrical section is housed in an extension building 200 ft. by 30 ft., two stories high and with a low basement. The building is full of English Electric control and motor equipment. In the basement there are 32 miles of B.I.C.C. cable and 20,000 electrical connections are involved.

Three fans draw air from outside the building and force it through a labyrinth filter which is periodically flooded with oil. The air is forced into the basement and up into the first-floor area. Some of the air flow is boosted by further fans and ducted to the main motors on the mill floor.

Electrical equipment

Total power rating of the English Electric motors used in the plant is 6,000 h.p. and maximum power requirement is 2½ mVA. The roughing and intermediate mills are driven by 6·2 kV., 600-h.p. slip-ring induction motor. The two intermediate finishing mills are split, each set of three stands being driven by a 500-volt, 500-h.p. motor, d.c. with variable-speed control. Each stand of the two finishing mills is fitted with a 500-V., 100-h.p. d.c. variable-speed motor. The 18 d.c. motors are fed from a pair of 1,250-kV. grid-controlled mercury-arc rectifiers.

The four rod coilers also have variable-speed d.c. motors of 65-h.p. rating, but these are fed from a pair of motor-generator sets, so that each motor has fully independent control to allow for coiling rod of different diameters.

The main control pulpit near to the roughing mill is the centre of operational control. Two other pulpits are arranged near to the finishing mills and in these provision is made for controlling the speed of each of the mills to ensure balance over the whole unit. An automatic system is incorporated in the electrical motor control to correct the mill speed under starting load when a fresh rod enters the rolls. By this device the speed of roll action is maintained very nearly constant under varying load. The three pulpits and the electrical control room are linked by microphones and loudspeakers so that there is immediate and constant contact between all members of the operating staff.

Of the one and a quarter million pounds that has been expended on the installation of this plant, the basic machinery cost about £500,000 and the electrical equipment some £300,000.

PEOPLE

The Engineering Group of the General Electric Co. Ltd., of England, announces the appointment of **Mr. J. L. Orme,** A.M.I.E.E., as deputy chief engineer for the London, Eastern and Southern areas. It will be recalled that Mr. E. W. Molesworth was recently appointed chief engineer for the same areas.

Mr. Orme was educated at Trent College and after joining G.E.C. as an apprentice in 1920 he was nominated by the company for a scholarship at Birmingham University. He returned to Witton Works and later spent three years as assistant branch engineer at the company's Cardiff branch.

In 1928 he moved to the Head Office of the company and later was appointed chief assistant to the manager of Central Stations Department, Mr. G. H. Mann, who retired on January 31 last. Although in his new appointment Mr. Orme will be associated with all the engineering activities of the company, his main interest will still be in the supply industry, in which he is well known.

Sir Ronald L. Prain, chairman of the Rhodesian Selection Trust Group of Companies, has relinquished the chairmanship of the Management Committee of the Copper Development Association after ten years in that office.

He has been succeeded by **Mr. E. C. Baring,** a director of the Anglo-American Corporation of South Africa Ltd., and vice-chairman of the Council of the Association of which Sir Ronald will remain as chairman.

Mr. H. R. Brunyee, at present works manager (services) at the Steel, Peech and Tozer branch of the United Steel Cos. Ltd., is to retire on July 31. He will be succeeded by **Mr. M. Thomas,** who is at present assistant works manager (services).

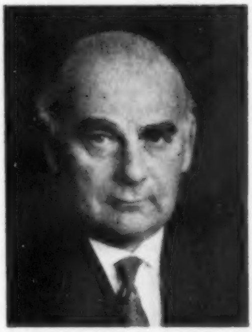
Mr. G. Syke, DIPL.ING., M.I.E.E., has been appointed a consultant to the Physics Department of the British Iron and Steel Research Association. He will be specially concerned with directing the work of the instruments section of that department.

Mr. Syke obtained a degree in electrical engineering at Berlin (1933). He joined Baldwin Instrument Co. Ltd. in 1943 as technical manager (later director) in charge of the Development Department. In this capacity he was engaged in the development and engineering of plant instrumentation and control schemes, mainly for the steel, rubber, paper and printing industries. In recent years he was particularly closely associated with the development of radio-active thickness gauges for hot and cold steel strip.

Mr. Syke started in practice as a consultant in 1955 and held appointments with the Steel Company of Wales Ltd. and Dunlop Rubber Co. Ltd. From 1956 to 1959 he was a member of council of the British Scientific Instrument Manufacturers' Research Association; he is a Member of the Society of Instrument Technology, Associate Member of the British Institute of Radiology and of the Hospital Physicists' Association.

Mr. H. H. Utley, A.M.I.MECH.E., F.INST.F., A.I.M., has been appointed managing director of Davy and United Roll Foundry Ltd. Mr. M. A. Fiennes, previously chairman and managing director, has thus relinquished the managing directorship, but remains chairman.

Herbert Henry Utley was educated at Rotherham Grammar School and the Applied Science Department of



Mr. H. H. Utley

Sheffield University. His career began as an engineering apprentice with the United Steel Cos. Ltd. at their Rothervale Works. After a period as assistant to the engineer, he transferred in 1931 to the companies' Central Fuel Department. In 1940 Mr. Utley took up an appointment with the Skinningrove Iron Co. Ltd. as night superintendent; nearly two years later he became assistant works manager. He left Skinningrove in 1945 to join Dorman Long & Co. Ltd. as assistant works manager of their Cleveland Works, and he was promoted to works manager in 1954. He left Dorman Long & Co. in 1957 to join Davy and United Roll Foundry Ltd. as director and general manager.

Mr. Utley, who has been a Member of the Iron and Steel Institute since 1941, is an Associate Member of the Institution of Mechanical Engineers, a Fellow of the Institute of Fuel and an Associate Member of the Institution of Metallurgists. He is a member of council of the Cleveland Scientific and Technical Institution, a member of the council of the Cleveland Institution of Engineers and served as their president in 1955-56.

The Yale and Towne Manufacturing Co. have announced the appointment of **Mr. R. W. Harris** as works director of the company's British Lock and Hardware Division and E. Tonks & Sons Ltd., Willenhall, Staffordshire.

Mr. Harris joined Yale and Towne as works manager in 1954. In his new appointment he is responsible for co-ordination of purchasing, design and development, standards, as well as entire production of all Yale and Etas locks, door closers and builders' hardware.

Induction furnace agreement

An agreement signed between the General Electric Co. Ltd., of England, and the British-Geco Engineering Co. Ltd., of Edenbridge, Kent, covers the design, manufacture and sale of induction furnaces, such that the resources and expert knowledge of the two companies in all matters relating to induction heating are combined.

The two companies have extensive facilities for research and development work covering all aspects of induction heating and are able to undertake the design and manufacture of all types of induction heating plants for ferrous and non-ferrous metals. The types include melting equipment, billet heating equipment, soldering and brazing machines, local heat-treatment plant and stress-relieving equipment.

BOOKS

Modern foundry practice

Edited by E. D. Howard. Third edition, Odhams Press Ltd. £1 10*s*.

Introduction to foundry technology

By D. C. Ebey and W. P. Winter. McGraw-Hill Book Co. £2 14*s*. 6*d*.

THE FIRST of these two books is the third edition of a book published in 1943 at, the reviewer believes, 8*s*. 6*d*. Both editions are very good books, each written by a team of specialist contributors—the third edition is on much better paper and is better bound. It can certainly be highly recommended as a very sound and extremely useful introduction to the complete range of modern foundry practice. It is noteworthy for the large number of clear line drawings of equipment.

One criticism that might be made is that the first four chapters on ferrous metals, heat treatment in the foundry, non-ferrous alloys and aluminium alloys are less useful than the remainder of the book since they repeat information most of which can be found in introductory texts on metallurgy. Furthermore, this information has to be compressed into about 110 pages and so will not always be comprehensible to the man without metallurgical training. The same criticism can be made of most of Chapter 5, 'Melting furnaces.' These chapters have, no doubt, been included in order to make the book complete. It is the remaining eight chapters that are the most useful since they cover very well actual foundry practice, books on which are much less common than on elementary metallurgy. There are chapters on pattern equipment, sands, moulds, coves, moulding machines, fettling and foundry practice.

The second of the books is described as an advanced version of a foundry-course manual used at Pennsylvania State University for engineering students. It is written in an abbreviated outline form which the authors say requires many less pages to contain the same information than normal writing. The reviewer is not convinced of the advantages of the abbreviated form, it certainly results in a book which is virtually unreadable, *e.g.*:

'2. Roe-baking time and temperature:

(*a*) Core-baking time varies with the binder used, the amount of binder and the amount of moisture in the sand;

(*b*) Core-baking time also varies with core size;

(*c*) Core-baking temperatures vary according to materials;

(*d*) Oil-bonded cores required oxygen in the oven atmosphere.'

There are 170 pages written in this style, there are then about 100 pages of operation and job sheets for practical work. These appear to be instructions for practical work or what the authors call 'practicium work.' An extract from one of these on cupola melting includes 'change to older clothing, preferably long-sleeved shirt and cotton twill or denim trousers, before reporting for class.'

In short, the book may well be useful as lecture and practical notes in a course on foundry practice, but apart from this cannot be recommended for use in this country. 'Modern foundry practice' is certainly to be preferred.

Progress in metal physics, Vol. 7

Edited by Bruce Chalmers. Pergammon Press, 1958. £5 10*s*.

THIS IS THE SEVENTH VOLUME of a very well-known and valuable series, all of which have been of a high standard. This volume contains five reviews. The first is 'Equilibrium diffusion and imperfections in semi-conductors' by J. N. Hobstetter of Bell Telephone Laboratories. The review covers especially the properties of semiconductors which are important in the wider aspects of metal physics and is divided into four main headings: electrical properties, equilibrium, diffusion and imperfections.

The second paper is by R. I. Jaffee of Battelle Memorial Institute and is on 'The physical metallurgy of titanium alloys.' It is a straightforward review of modern work.

The third is by Larry Kaufman and Morris Cohen of the Massachusetts Institute of Technology and is on 'The thermodynamics and kinetics of martensitic transformations,' and describes the diffusionless, shear transformations named after the austenite to martensite transformation in steels.

The fourth review is 'The stored energy of cold work' by A. L. Titchener of the University of Auckland and M. B. Bever of the Massachusetts Institute of Technology, which reviews the many methods that have been used to determine the stored energy and discusses the theory of the subject.

The fifth review, by H. M. Rosenberg of the Clarendon Laboratory, Oxford, brings up to date the review by MacDonald in Vol. 3 of 'Progress in metal physics,' which dealt with the specific heat and electrical resistance of metals at low temperatures. Rosenberg also discusses other properties of metals at temperatures below 90°K., including creep at liquid helium temperatures and mechanical properties.

The book illustrates very well the complexity and volume of modern metallurgical research. The reviews are generally too detailed to be read by people who are only interested in the subjects; they are written by specialists for specialists and budding specialists.

The physical metallurgy of magnesium and its alloys

By G. V. Raynor. Pergammon Press, 1959. £3 15*s*.

THE CONTENTS of this book by Professor Raynor are by intention accurately described by its title. As he says in his preface, '. . . there has been a steady advance in our knowledge of the electronic structure of magnesium, the influence of this on alloying characteristics, the general theory of alloying and the constitutions of magnesium alloys . . . and it appeared to the author that it would not be inappropriate, at the present time, to survey the theoretical background to the subject of magnesium alloys.'

What Professor Raynor has set out to do, he has succeeded in doing very well and his book of 531 pages contains a great deal of lucid information on the subjects listed; to a metallurgist or metal physicist carrying out research into magnesium and its alloys, the book will be indispensable. However, it is not a book for engineers or for technologists; apart from a brief introduction practical matters are only considered in so far as they illustrate the more theoretical aspects. There is a chapter, Chapter XVII, 'Summary of the influence of alloying on the mechanical properties of magnesium,' but it is only 22 pages long and a page and a half of these deal with electrical resistivity. J. H. RENDALL

EXHIBITIONS

This is the season of exhibitions, and both in London and other important centres many interesting displays have and are taking place. To describe them all adequately is, unfortunately, not possible, so we have selected certain points of interest without any claim to be representative. It was noticeable that there was an increased emphasis this year on mechanization in all the exhibitions visited—a welcome reflection on the fact that Britain is now one of the leading countries in the field of instrumentation export.

THE FUEL EFFICIENCY AND POWER for Industry Exhibition was held at Olympia last month.

Lafarge Aluminous Cement Co. Ltd. demonstrated the wide uses for refractory and insulating concretes made with their products, Ciment Fondu Aluminous Cement and Secar 250 White Calcium-aluminate Cement. Exhibits included ignition and stoker arches, burner blocks, flat roof block, furnace doors and lid, combustion chamber units, sectioned high-duty combustion chamber and samples of the various cements and the various aggregates to go with them. The company also exhibited a new synthetic aggregate called Alag for use with Ciment Fondu high alumina cement, the resultant concrete attaining superlative qualities of density, hardness and strength in 24 hours, and is also heat resistant.

A refractory concrete construction has the same dimensions at 1,000°C. as it had when cast, because the small contraction due to the elimination of water on first firing practically neutralizes the thermal expansion. To illustrate this an automatic device showed two special shapes made with this material, one fired and the other non-fired, and the demonstration alternately married and separated the two pieces.

The accepted trend in furnace operation today is towards higher output, higher temperatures and more severe operating conditions. Unless the refractories used keep in step with these demands, heavy maintenance costs and shut-downs may well wipe out the advantages gained by extra efficiency and higher output. Moreover, refractories in poor conditions tend to push up fuel consumption and in this respect there is a direct connection between the efficiency of fuels and the quality of refractories.

Super-duty refractories are usually thought of in the form of squares and shapes, kiln fired during manufacture, but **Morgan Refractories Ltd.**, of Neston, Wirral, Cheshire, have developed a range of castable and mouldable refractories that can be fired *in situ* and yet have a performance comparable to that of the best super-duty pre-fired refractories. This is called the TRI-MOR range of castable and mouldable refractories and examples were on show.

Traditional and special refractories were featured in other sections of the stand, giving representative coverage to some of the many products manufactured by Morgan Refractories Ltd. These included bricks, furnace shapes, assay ware, tubes, sheaths, and 'Purox' very high purity ceramic oxide refractories for use in the temperature range 1,950–2,600°C.

The iron and steel industry is spending nearly £200,000,000 annually on fuel and power. The amount represents about one-fifth of the total production cost and naturally the industry is making steady efforts to reduce fuel and power consumption by every possible means.

Some open-hearth furnaces have been radically modified to be operated on oxygen instead of normal fuels. This change-over stepped up production by up to 100% and reduced the average fuel consumption to about one-fifth.

This method of increasing steel output has been applied to large open-hearth tilting furnaces, used for

A fully-working heat-treatment shop was exhibited by the Gas Council at the Fuel Efficiency and Power for Industry Exhibition. The plant was working not only for the benefit of visitors; it was dealing with part of the work schedule transferred from the West Midlands Gas Board's heat-treatment shop at Birmingham. Working equipment included a bright-annealing furnace (the Incandescent Heat Co. Ltd.); high temperature oven (Thermic Equipment and Engineering Co. Ltd.); tempering oven (J.L.S. Engineering Co. Ltd.); hardening and tempering salt baths (I.C.I.); flame-hardening machine for hardening spindles (Peddinghaus equipment—Surfard Ltd.). Furnaces too large for inclusion in the exhibition were displayed in model form.

making a wide range of steels from pig-irons of varying types, including highly phosphoric iron. The materials are crushed and screened, and the ore 'fines' are sintered before smelting. Mainly by extending sintering and ore preparation the industry has reduced the quantity of coke required per ton of iron by 27% since 1945.

A further factor contributing to increased efficiency of the industry is the replacement—now virtually complete—of hand mills by continuous or semi-continuous mills.

The British Iron and Steel Federation display showed major aspects of a fuel efficiency and clean-air programme carried out by the steel industry as part of its £1,000 million development programme which will be completed by 1962. It has resulted in greatly improved amenities and a marked conservation of fuel.

The Production Exhibition

The Fourth Production Exhibition was held at Olympia, London, in April. The exhibition was selective, and all exhibits related to the topic of producing goods more cheaply and efficiently.

In addition to exhibits by Development Associations, such as the British Electrical Development Association and the Tin Research Institute, the British Productivity Council, the Central Electricity Generating Board, the British Association for Commercial and Industrial Education, the British Standards Institution were exhibiting, as well as management advisory services.

The evaluation of the 'solderability' of metal surfaces is a long-standing need in industry. The **Tin Research Institute** demonstrated a device which enables a technically trained operator to obtain a precise indication of soldering quality in a few seconds. For convenience in observing the test, it was magnified through a Marconi closed-circuit television system.

The method requires a standard test specimen in the form of a strip 3½ in. long by ½ in. wide. On this strip is placed a pellet of solder and some flux. Heat is generated in this strip by passing a large current, so that the pellet melts and spreads out. The final area of spread attained is a measure of the soldering quality of the strip.

By standardizing the type of strip but varying the solder pellets, it is possible to compare the value of solders; similarly fluxes can be compared. A range of typical test samples was exhibited. The method is particularly suitable as a laboratory tool for electronic equipment manufacturers.

There is a great variety of electric motors and associated control gear available to industry, and to help in the choice of equipment the **Electrical Development Association** has published a book, *Electric motors and controls*.

On their stand exhibits included many types of infinitely variable speed drives and electrical, mechanical, hydraulic as well as some recently introduced methods were covered.

Sir W. G. Armstrong Whitworth Aircraft Ltd., member of the Hawker Siddeley Group, who already have a tradition in the atomic energy field, have developed new methods for machining beryllium and have recently opened a new factory.

On its stand at the Production Exhibition A.W.A. showed examples of finely machined beryllium, together with details of the new factory with its totally-enclosed machines, laboratories and elaborate precautionary systems which virtually eliminate the dust hazard.

Also on display was an example of a reactor fuel can machined from magnesium alloy, as well as cans machined from stainless steel.

Electronics and automation

The Instruments, Electronics and Automation Exhibition was held at Olympia last month. The exhibitors numbered 500 and were representative of 15 different countries, emphasizing the international character of this exhibition. The size of the exhibition has increased so greatly that two of the main halls were required at Olympia this year.

Part of their book, *Process integration and instrumentation*, was 'brought to life' on the **Electrical Development Association's** stand.

The exhibit illustrated one section of the book and covered level control for solids, liquids and gases. The types shown included isotope, photo-electric, conductance, capacitance, resistance back-pressure air and float apparatus.

An all-British colour television camera was shown on the stand of the manufacturers, **E.M.I. Electronics Ltd.**

The E.M.I. colour camera, which is light and compact, uses three vidicon tubes and a new optical system, several times more efficient than relay lens systems, which has been designed so that the maximum amount of light falls on the photo-conductive surfaces of the vidicons. This gives an improved colour quality, even under difficult lighting conditions. The design makes the system suitable for broadcasting as well as for use on closed circuits.

Another new development of considerable interest on the E.M.I. stand was a stereoscopic television system which utilizes two closed-circuit camera channels. The pictures from these are superimposed on each other to form a single three-dimensional image. This system has been designed for use in nuclear plants and other establishments where dangerous materials are handled remotely.

Three-dimensional television for use in industry was shown by **Pye Ltd.** The new system can be attached to any existing closed-circuit television installation. This is the first time in Britain that a 3-D television picture has been made possible when using only one chain of closed-circuit television equipment.

A Pye master slave manipulator can be used in conjunction with the new 3-D equipment for remote handling. The operator, having stereoscopic vision, can pick up any article by remote control. The three-dimensional effect is obtained by a mirror beam splitting system at the camera position and an arrangement of mirrors at the monitor end.

Prominent among non-destructive test equipment is the Introview Flaw and Corrosion Detector being shown by **Sperry Gyroscope Co. Ltd.** for the first time as a test instrument for stainless steel tubing. Introview has been used for some years for quality control in tube manufacturing plants and the *in situ* inspection of ships' condenser tubes. The addition to the standard Introview equipment of high-frequency converters and probes enables tests to be made for manufacturing defects in materials of low conductivity. A stringent quality control is provided by Introview, in that traces are marked on permanent charts to give the inspector a lasting record of the condition of the manufactured tube. The display features the complete equipment testing austenitic steel samples. The Introview equipment is manufactured and marketed by Sperry under licence from I.C.I. Ltd.

Different versions of the Cambridge Electronic Re-

corder were prominent on the stand of the **Cambridge Instrument Co. Ltd.** The intention was to demonstrate the flexibility and versatility of this instrument and to show some examples of the wide range of primary measuring elements, analysers, transducers, etc., that the company had designed and manufactured for applications in industry.

The electronic recorder forms part of complete equipment manufactured by the company for temperature measurements, radiation intensity, gas analysis, determination of pH values, electrical conductivity of solutions and calorific value of gases, the measurement of dissolved oxygen, hydrogen, and residual hydrazine in feed water, etc., and is supplied also as a single unit for many other applications in science and industry.

Kelvin & Hughes (Industrial) Ltd. showed a new data-handling system for the first time. This flexible system for rapid scanning and logging of numerous process variables, *e.g.* temperature, pressure, flow, strain, pulse or a.c. outputs, offers digital presentation and various facilities, including high and low limit checking, with alarm indication, range variation, linearization, etc. Any number of inputs can be scanned at a rate of 5/sec. and logged at a rate of 1/sec. System sensitivity is 10 microvolts and the accuracy of reading is 0·1%. Other items included an automatic boiler control system, which is demonstrated by an interesting simulator unit, a range of transistorized temperature controllers, high-speed pen recorders and equipment for non-destructive testing of materials.

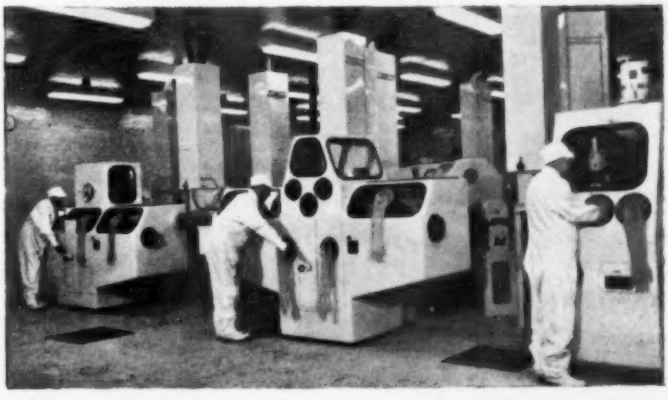
Honeywell Controls Ltd. had a display of industrial instrumentation which included conventional and miniature indicators, recorders, and electric and pneumatic controllers for flow, pressure, liquid level, temperature, differential converters for flow and liquid level, ElectroniK temperature transmitters, millivoltmeter controllers, blind controllers, Radiamatic radiation pyrometers, accessories, including electric and pneumatic motorized valves, thermocouples.

Intrega, Leeds & Northrup Ltd. showed exhibit comprising Speedomax G and H recorders and controllers for temperature, millivoltage, conductivity, pH and Redox, and many other variables including resistance, electrical and mechanical load, position, speed, smoke density. Instruments in operation included a console demonstrating Speedomax performance with L and N Series 60 units for position, duration and current-adjusting control.

Ether Ltd. and Electro Methods Ltd. were showing a complete range of temperature measuring and control instruments, including millivolt and potentiometric types. Both indicators and recorders will be shown together with various forms of control equipment. Control cubicles completely wired were also shown. In addition, solenoid valves for all gases and fluids were on view, most notable being the range of plastic body valves. Also on this stand were low inertia motors, relays, cartridge thermostats, solenoids, magnetic amplifiers, automatic voltage regulators, toroidally-wound saturable reactors and a wide range of printed circuit connectors and miniature plugs and sockets. One of the attractions was the new 'Xactrol' Potentiometer Recording Controllers, Series 2000, with the patent zero-load and zero-differential control systems.

Four divisions of the **English Electric Co. Ltd.** were exhibited: Data Processing and Control Systems, Meters

The Introview equipment, of the Sperry Gyroscope Co. Ltd., checking samples of specially treated tubes to demonstrate the effects of manufacturing defects, wall thinning, etc.



General view of Armstrong Whitworth Aircraft's Beryllium Machining Plant showing the totally enclosed machines with the operators in their sterile overalls, caps and surgical boots.

Relays and Instruments, Transformer, and the Instrument Wing of Guided Weapons. One exhibit was a quality control instrument, a direct reading permeameter for measuring the permeability of small samples of magnetic material, *e.g.* having a cross-sectional area as small as 0·006 sq. cm. This is important for the elimination of unsuitable magnetic components for equipment such as small precision motors and synchros. The degree of permeability can be directly read from a sensitive meter by an unskilled operator. It is believed to be the first instrument available to do this operation without needing calculation or skilled operators. Although primarily intended for high permeability alloys, measurements can be made on other materials, *e.g.* Permendor and silicon steel.

Elliott-Automation Ltd. had three stands at the exhibition. The main exhibit was a complete Panellit 609 industrial information system which incorporated as its central controlling unit an Elliott 803 digital computer.

Process control was represented by displays from Electroflo Meters Co. Ltd., James Gordon & Co. Ltd., and the Process Control Divisions of Elliott Brothers (London) Ltd.

New electronic instruments were shown on the stand of the DIA Elektrotechnik of East Germany, for whom **Griffin & George Ltd.** act as British agents.

One of these was the Ultra-sonic Material Tester where there is no contact between the testing equipment and the material being tested. The principle is that of magneto-striction, an ultra-sonic wave being induced in the material being tested by means of a magnetic coil. The defects are shown up like Radar signals on an oscilloscope. This tester can also be used for continuous testing of strip or rod production, faults being automatically treated so as to produce perfect results.

The stand of **Lancashire Dynamo Electronic Products Ltd.** was one of the two largest in the exhibition. It was dominated by a 20-ft. tower carrying a large-sized facsimile of the scale of the new range of circular chart indicator/recorders. The pointer, controlled remotely through an encapsulated transistorized positional servo system, demonstrated the capabilities of the new miniature packaged servo system. A very wide range of equipment was shown, including a resistance welding control installation.

Mechanical handling

The Rt. Hon. Reginald Maudling, President of the Board of Trade, opened the Mechanical Handling Exhibition last month at Earls Court, London. This was the biggest and most comprehensive display of labour-saving machinery and systems so far, covering the whole range of equipment from hand trucks to complete factory-handling installations.

Exhibits of interest to the metal industry at the exhibition were shown by the following companies:

Cutler Conveyor Co.: A new special type of tilt pan chain conveyor which has been specially designed to handle die-casting for a new £2,000,000 die-casting factory.

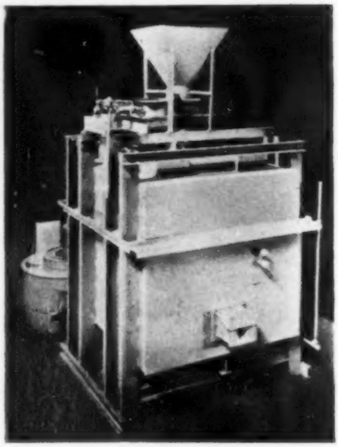
S. Parsons & Co. Ltd.: Weighing machines and weight control units of particular interest to the foundry trade.

Tirfor Ltd.: Pulling and lifting machines—scaffold winches, etc.—all fully portable used in the steel industry.

W. E. Burnand & Son Ltd.: A half-scale model of a new 25-ft. long electro-magnetic lifting beam for lifting steel plates was shown.

Ewart Chainbelt Co. Ltd.: One of the largest monorail conveyor buckets and chain in operation in the country —used on a foundry cooling conveyor—was shown.

NEWS



Aluminium melting and holding furnaces

A dry-hearth aluminium melting furnace with a companion holding furnace, both of American design, are now being made in this country by the Electric Resistance Furnace Co. Ltd.

The two furnaces form a central installation for melting up to 500 lb. of aluminium an hour for die casting, mould and sand casting, and for recovering aluminium from scrap. The metal can be ladled direct from the holding furnace or tapped off and delivered hot to other holding furnaces.

The aluminium scrap is charged into the furnace hopper, where preheating begins. As it moves into the furnace it collects on and above a sloping dry hearth of silicon carbide and is contained in a vertical cylindrical muffle heated externally by silicon carbide elements. The molten metal is directed by the hearth through a covered trough, where it runs out without overheating to be maintained in the holding furnace at the precise temperature required. To prevent oxidation, the aluminium is melted and held at temperature in an atmosphere of high-purity dry nitrogen. Oxide present in the scrap collects on the hearth and can be raked out through a plug door at the back. This door can be used for inserting ingots. The melting furnace is rated at 100 kW., the holding furnace has a capacity of 1,500 lb. and a rating of 20 kW.

High-speed rolling of aluminium-alloy strip

A SENDZIMIR cold strip mill has been installed at the Woodgate Works, Quinton, of Birmetals Ltd. The mill —the first of its kind in Europe devoted to the rolling of aluminium alloys—has cost £1,000,000, and when in full operation it will roll between 12,000 and 20,000 tons of aluminium sheet per year.

The mill itself is a 50-in. reversing mill capable of rolling aluminium alloys in coil form at speeds up to 1,600 ft. per min. The finished width of the coil obtained is 48 in. and the thicknesses which can be produced range from $\frac{3}{16}$ in. (0·1875 in.) down to as little as 0·006 in. Automatic tension control and continuous measurement of gauge are incorporated in the mill.

continued on page 262

News

concluded from page 260

The $2\frac{3}{8}$-in. dia. work rolls are ground to very high precision to give absolute uniformity across the width of the strip and a roll-change in the mill can be effected in less than a minute.

When the mill is in full operation it will finish-roll between 12,000 and 20,000 tons of sheet per annum according to average final gauge (this tonnage is the equivalent of 35,000/60,000 in steel). To obtain the maximum benefit from the mill it is necessary to feed it with the longest possible coil from earlier operations. It will take a coil up to 10,000 lb. in weight, but the coil being rolled at the present time weighs just over 8,000 lb., which is equivalent to 11 tons in steel.

To be able to cast a rolling slab capable of producing a single coil of this weight, and to have a hot mill capable of rolling this super slab, would have meant an estimated capital outlay by the company of another £2,000,000, and would have put out of work some of the existing plant. This was not considered an economical proposition, so that the idea of welding together a number of smaller coils with the desired width to form a heavy coil was considered and a scheme formulated for flash-butt welding of strip up to 52 in. wide.

The result is that the welding line, which is composed of a number of ancillary units and the flash-butt welding unit, now forms a complete unit producing the desired heavy coil demanded by the Sendzimir mill.

Many other items of equipment, all of which have had to have special attention to technical detail, have been incorporated in the whole scheme. Such items are a coil-annealing furnace, slitting line, cut-to-length line, and sheet-annealing furnace incorporating a flash-annealing furnace 40 ft. long followed by a cooling chamber 42 ft. long. Continuous tapes carry the sheets through the furnace at a speed of up to 100 ft. per min. Because of the unusual length of this furnace, many tests over an extended period of time had to be undertaken to ensure uniformity of annealing in the sheets. This uniformity has now been achieved.

The foundations for the mill, concrete and reinforcements, weighed a total of 2,500 tons and in addition there are miles of piping and cable ducting beneath the floors. The underground work, together with the electric and electronic equipment, accounted for a large proportion of the total expenditure.

Essay competition

Research is this year sponsoring the Waverley Gold Medal Essay Competition for the eighth year in succession. The competition is designed to encourage the scientist and the engineer to express his views and translate his work into an essay that will be readily understood by other scientists, directors of industrial firms and others interested in science and technology.

Further details, if required, can be obtained from the editor of *Research*, 4/5 Bell Yard, London, W.C.2. The last date of entry is July 31, 1960.

New address

The new London address of Brayshaw Furnaces Ltd. is 232 Bishopsgate, London, E.C.2 (Tel. Bishopsgate 3575/6).

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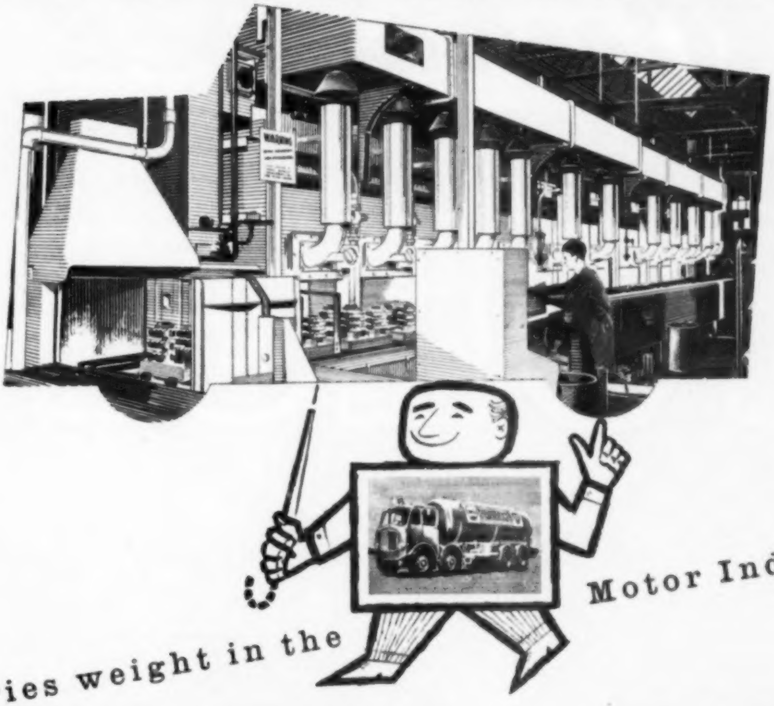
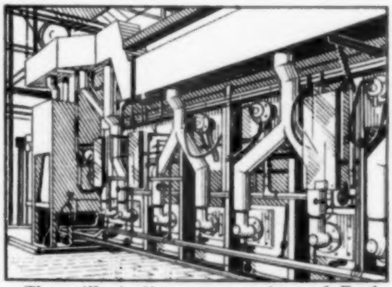


carries weight in the Motor Industry



These illustrations, by courtesy of Ford Motor Co. Ltd, show two of many continuous gas carburizing furnaces installed at their Dagenham factory, using endothermic atmospheres produced from PROPAGAS.

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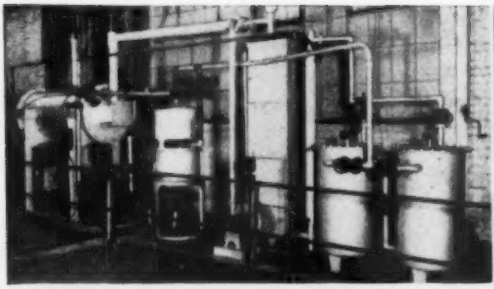

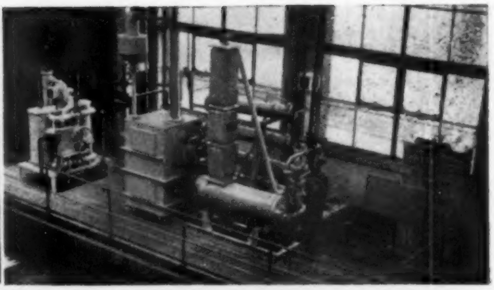

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Top left: A conventional exothermic plant, with primary and reactivated secondary drying units and equipment for removal of sulphur compounds.

Top right: A fully automatic plant for producing commercially pure nitrogen with extremely low dewpoint.

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